Bilateral Market Structures and Regulatory Policies in International Telephone Markets

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Abstract

We develop models of bilateral oligopoly with two-way traffic exchanges to study the impact of competition and government regulatory policies on the international telephone markets. When carriers in each country are required to act collectively in setting a uniform settlement rate for inbound traffic, the proportional return rule (PRR) inflates equilibrium settlement rates and neutralizes equilibrium calling prices, although a direct effect of the PRR is to lower domestic calling prices for fixed settlement rates. Both competition and the PRR tend to increase net settlement payments. The overall market efficiency can be achieved only when multiple channels are available for traffic exchanges. Using a panel of 47 countries that exchanged telephone traffic with the U.S. between 1992 and 2004, we test the effects of bilateral market structures and the U.S. government policies on calling prices and settlement rates and the empirical results support our theoretical findings.

JEL Classification: L13, L5 and L96

Key Words: bilateral oligopoly, competition, settlement rate, settlement payment, proportional return rule, international telephone, regulatory policy

1 Introduction

The completion of an international telephone call involves two major components. A domestic carrier collects the call from the caller, and then a foreign counterpart terminates the call by delivering it to the receiver. Access to the foreign carrier’s network is an essential and complementary input for the domestic service provider. A service payment, often called the “settlement rate” on a per-minute base, is made from the domestic to the foreign carrier. Moreover, international telephone calls typically flow in two directions, and a carrier often provides both originating and terminating services. In the jargon of industrial organization, a carrier in this market typically combines the roles of both downstream and upstream players in a traditional vertical framework, receiving two sources of revenues from retail services and input supplies. These two revenues of a carrier can be interrelated, depending on government regulatory policies on the settlement arrangement between the interconnecting carriers. The revenues can also be affected by the competition for providing call-originating and call-terminating services on each side of the market. In this paper, we study

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how such two-way bilateral market features, combined with competition on each side of the market of facility-based message services, affects the determination of settlement rates and calling prices. We also consider whether government policies, particularly the policies implemented by the U.S. government, are effective to gear the market outcomes toward its claimed goals to improve efficiency and balance the settlement payments between countries.

■ Two-way bilateral market structures, competition, and the FCC’s involvement.

The bilateral market structures are evolving, and governmental policies have changed several times. In the late 1970s, the U.S. unilaterally introduced competition in its domestic market for international telephone services, whereas the markets in other countries remained monopolized by single national carriers. Competition on the U.S. side lowered its calling prices, but also resulted in rising net settlement payments to other countries. Under this bilateral market structure, the foreign monopolist could play one carrier against the others in order to reduce the rates it paid to the U.S. carriers for traffic delivery in the U.S. and increase the rates the U.S. carriers paid for terminating traffic in the other country, a strategy often called “whipsawing”. Both the U.S. carriers and the Federal Communications Commission (FCC) deemed the unequal positions in exchanging traffic to be the main reason for high settlement rates paid by the competing U.S. carriers, and, hence, for the high consumer calling prices in the U.S. (FCC (1999))

This concern arising from the traffic exchanges with foreign monopolies called for government intervention in settlement negotiations. In 1986, the FCC initiated its International Settlements Policy (ISP), intended to prevent foreign monopoly carriers from engaging in whipsawing. The ISP consists of three major rules: 1) Uniformity: All U.S. carriers must pay the same settlement rate for the outbound traffic on the same route; 2) Reciprocity: The U.S. carriers must receive the same rate for terminating inbound traffic as the rate paid for outbound traffic; 3) Proportional Return Rule (PRR): Traffic from a foreign country is allocated among the U.S. carriers in proportion to their shares of outbound traffic to that country. Limiting their aggressive competition in providing call-termination services, those requirements tied up the competing carriers’ interests and let them behave as a single entity when negotiating settlement terms with foreign monopolists.

However, the ISP policy did not result in sufficiently low retail calling prices, instead in ever-growing net settlement payments to foreign countries. In 1997, the FCC claimed that the outcomes were due to the high settlement rates and the lack of foreign competition. It then released its Benchmark Order (FCC 1997), which set up tight upper bounds on settlement rates negotiated by carriers. Additionally, since the late 1990s, many other countries started to introduce competition into their domestic markets. The FCC responded by relaxing its ISP policy. As shown in FCC (2004), when a country that interconnects with the U.S. carriers is considered to be competitive, the ISP is lifted from the negotiation of settlement agreements on this route.

■ Overview of the model and empirical analysis.

Our main objective in this paper is to provide a framework for analyzing the impacts of competition and government regulatory policies on equilibrium retail calling prices, settlement rates, and net settlement payments in international


2Several other countries, including the UK, Finland, Sweden and Mexico, adopted policies similar to the ISP, as noted by Malueg and Schwartz (2001) and Wellenius, Galarza, and Guermazi (2005). The adoption of the ISP policy by the Mexican telecommunication authority caused a dispute between the U.S. and Mexican governments through the World Trade Organization in 2000, see Wellenius, Galarza, and Guermazi (2005).

3Within a prescribed transition period, the order required all U.S. carriers to negotiate settlement rates to be less than or equal to 15 cents for upper-income countries, 19 cents for upper- and lower-middle-income countries, and 23 cents for lower-income countries (FCC 1997).
telephone markets, taking into account the two-way bilateral market structure with competition and specific settlement arrangements on each side of the markets. We adopt two-stage games to approach the industry. In the first stage, carriers from two representative countries choose settlement rates. In the second stage, domestic carriers on each side compete for outgoing calls in a Cournot fashion.

In our core model, Settlement Alliances, government regulation in each country requires that domestic carriers behave collectively in setting a uniform settlement rate for inbound traffic and use a linear combination of the Equal Sharing Rule (ESR, whereas the carriers share the incoming traffic volume equally) and the PRR to share incoming traffic volume (or equivalently, to share incoming settlement payments). The PRR is an important policy instrument required by the FCC. Under this requirement, a competing carrier’s share of terminating inbound traffic is linked with its market share of the outbound traffic. This linkage (or “bundling” the two-way service markets) could affect carriers’ decisions on both originating and terminating services. Essentially, in this setting, settlement rates are determined cooperatively within an alliance of carriers in each country, but non-cooperatively across countries.

One particular contribution in our paper is a formal analysis of the PRR with endogenous determination of settlement rates. The PRR adopted in a country puts downward pressure on the domestic calling price if settlement rates are fixed. However, when settlement rates are strategically determined, as in our core model of Settlement Alliances, we show that the PRR inflates equilibrium settlement rates, neutralizes equilibrium calling prices, and shifts settlement payments (through settlement rates) from domestic carriers to foreign carriers. Consequently, carriers in a country jointly prefer the ESR to the PRR. We also show that as the degree of domestic competition increases, both total payouts and net payments from domestic carriers to foreign carriers increase. We further illustrate that the relationship between the number of domestic carriers and the settlement rate they pay tends to differ from the one in the traditional vertical model.

To compare the outcomes with and without the government regulations, we extend our analysis to consider two other market settings. The first one corresponds to a “whipsawing” situation in practice. Between this equilibrium outcome and the one in Settlement Alliances, we find that domestic competition and the PRR introduced in one country tend to increase settlement rates and its net settlement payments to other countries. In the next setting, we relax the requirement for collective rate-setting in the core model and allow for multiple channels of international traffic exchanges with independent determination of settlement rates. We conclude that the overall market efficiency can be improved without the PRR when multiple channels are available for international traffic exchanges.

Using a panel dataset covering 47 countries that exchanged international telephone traffic with the U.S. carriers between 1992 and 2004, we test the marginal effects of bilateral market structures on the settlement rates and calling prices - particularly, how the domestic competition effects on those economic variables are altered by the foreign market structures. In our empirical analysis, we control both the individual route and time fixed effects, as well as individual time trends in those outcome variables. We argue that the effects are driven by both the feature of traffic exchange and the regulatory policies. In exchanging traffic with concentrated foreign markets, the FCC’s imposition of ISP would weaken the roles of domestic competition on calling prices; while with un-concentrated ones, the relaxation of the policy would lead the price more responsively to competition.

Related literature. Our work tries to fill a gap in the industrial organization literature on
Bilateral monopoly structure in the international settlement is well studied in the literature (for examples, see Carter and Wright (1994), and Cave and Donnelly (1996)), where both cooperative and non-cooperative determinations of settlement rates are considered and compared. There are a few papers studying the impacts of competition in international telephone markets. Yun, Choi, and Ahn (1997) and Wright (1999) analyze the effect of competition on uniform and reciprocal settlement rates. Assuming that symmetric domestic carriers compete à la Cournot in the retail market and divide the foreign inbound traffic for call-termination services evenly, Yun, Choi, and Ahn (1997) find that the desirable settlement rate for carriers as a group in each country increases with both domestic and foreign competition. However, they do not formally analyze how settlement rates are determined. In the analysis of Wright (1999), two domestic carriers in a Hotelling model use the PRR and jointly bargain with the foreign carrier over a uniform and reciprocal settlement rate via Nash bargaining, where the degree of product differentiation between the two carriers is used to measure the degree of competition in the retail market. His simulation results illustrate that the introduction of competition in one country tends to reduce the domestic retail price, but also to increase the settlement rate and foreign retail price. Wright (1999) further applies a reduced-form approach to empirically check the determinants of settlement rates. Among others, he argues that foreign competition could be an important factor in lowering the settlement rates paid by the U.S. carriers in his sample period. Galbi (1998) and Rieck (2000) also study the effects of the PRR and retail competition among domestic carriers on retail prices, and they notice a price distortion created by the PRR. However, in their studies, settlement rates are exogenously given. Other impacts of the PRR are studied by Malueg and Schwartz (2001), illustrating that the PRR creates incentives for some U.S. carriers allied with foreign monopolists to use traffic re-routing practices to reduce settlement payments to non-alliance members, harming U.S. consumers.

Our analysis is related to the industrial organization literature on local telecommunications networks. For example, Armstrong (1998) and Laffont, Rey, and Tirole (1998a) (1998b) focus on access charges and competition in local telecommunication networks. A typical feature in local networks is that interconnecting carriers compete for the same set of subscribers. As such, the two revenues that a carrier receives from retail services and access provision are strategically inter-related. Depending on its level, access charges can be a tool to either facilitate carrier collusion or enhance market competition. Policy design on access charges must then take into account carriers’ strategic interactions. In international telephone markets, interconnecting carriers are not in the same retail market, but they also derive two sources of revenues, one from call-initiation in its own country and the other from call-termination from foreign countries. We find that whether these two revenues are strategically interrelated is affected by the government PRR policy, even when the demands for international phone calls in the two countries are independent of each other. The strategic link between the two sources of revenues can potentially distort the benefits of competition through high settlement rates.

In the next section, we lay out our model fundamentals: demand, costs, and market structures. Section 3 provides an equilibrium analysis of our game of “Settlement Alliances”, in which carriers in each country behave collectively in setting a uniform settlement rate for inbound traffic and

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4 See Armstrong (2002) and Einhorn (2002) for extensive reviews of the literature on international telephone markets.

5 Motivated by the theoretical framework in Yun, Choi, and Ahn (1997), Madden and Savage (2000) provide an empirical study to explain the pattern of calling prices in international telephone markets between the U.S. and foreign countries. In their study, they assume exogenous settlement rates and the ESR.

6 Policies can take the form of direct regulation of access rate, or of a prescription on carriers’ negotiation behaviors.
use a linear combination of the ESR and PRR to split incoming settlement payments. Section 4 analyzes a modified model with a foreign monopolist “whipsawing” competing domestic carriers without government regulation. We further compare the equilibrium net settlement payments in the “whipsawing” game with those in the game of Settlement Alliances. In section 5, we extend our basic framework to allow for multiple channels for international traffic exchanges. Section 6 discusses our theoretical findings in the context of the U.S. market for international telephone services and empirically analyzes the settlement rates and calling prices in the U.S. by panel data models. The last section concludes. All proofs are collected in an Appendix.

2 A Bilateral Two-Stage Oligopoly Model

This section lays out our primary model of bilateral oligopoly, which has been inspired by the bilateral market structure in the international telephone markets prior to deregulation in most countries. Our modeling approach is to incorporate regulatory rules on traffic exchange across countries and traffic division within a country into a traditional framework of Cournot competition.

Demands and costs. Consider two representative countries, A and B. In our discussions below, A is often referred to as a domestic country, and B as a foreign country. There are demands from consumers in each country to make phone calls to the other country. For simplicity, we assume international telephone services in each country are a homogeneous product. The inverse demand from consumers in each country to make phone calls to the other country. For simplicity, we assume below, A countries and traffic division within a country into a traditional framework of Cournot competition.

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Country A has \( m \) identical international telecommunication carriers, each of which is capable of providing both call initiation and termination services, and similarly, B has \( n \) identical carriers. Each carrier in country A incurs a marginal (per-minute) cost \( c_A \) to initiate outgoing calls and \( d_A \) to terminate incoming calls, and similarly for carriers in B, with \( c_B \) and \( d_B \).

We make several assumptions on demands and costs, which will be maintained throughout the paper.

Assumption 1 For \( X \in [0, \bar{X}) \) and \( Y \in [0, \bar{Y}) \), (i) \( P_A(X) \) and \( P_B(Y) \) are twice continuously differentiable; (ii) \( P'_A(X) < 0 \) and \( P'_B(Y) < 0 \); and (iii) \( 2P'_A(X) + P''_A(X)X < 0 \) and \( 2P'_B(Y) + P''_B(Y)Y < 0 \).

Assumption 2 \( \lim_{X \to 0} [P_A(X) + P'_A(X)X] > c_A + d_B; \lim_{Y \to 0} [P_B(Y) + P'_B(Y)Y] > c_B + d_A. \)

Assumption 1 is widely used in the literature on monopoly pricing and Cournot competition. It guarantees uniqueness of Cournot-Nash equilibrium and monopoly profit-maximizing quantity. Assumption 2 implies that an integrated monopolistic operator across two countries can profitably provide both call initiation and termination services in each direction.

Timing of the game. We consider a two-stage game. Carriers choose their settlement rates in the first stage, followed by their choices of call volumes in the second stage.\(^8\) In the first stage, all

\(^7\)Here, we follow Armstrong (2002) and assume that there are no cross-price effects for calls across countries. Based on a data set for calls between the U.S. and 17 West European countries from 1979 to 1986, Acton and Vogelsang (1992) provide empirical evidence that cross-price effects are generally not statistically significant.

\(^8\)In the case of bilateral monopolies, Armstrong (2002) provides justifications for this sequential-move structure and discusses both cooperative and non-cooperative determinations of settlement rates across countries.
carriers in each country are required to form an alliance and choose a uniform settlement rate for the traffic from the other country, maximizing the alliance’s total profits; while the carriers in the other country simultaneously do the same for their incoming traffic. Let \( r \) be the settlement rate chosen by the carrier alliance in \( A \), and \( s \) be the per-minute rate chosen by carriers in \( B \) for the traffic coming from \( A \).

In the second stage, given a pair of settlement rates \((r, s)\), carriers in each country simultaneously compete in Cournot fashion for outgoing traffic, with each carrier choosing the size of call volume that it wants to carry over to the other country. Incoming traffic volumes are shared among carriers according to a pre-defined division rule which we will specify next.

**Incoming traffic division rules.** We consider two basic rules for dividing incoming traffic volumes from the other country, as well as a linear combination of them. The first is the Equal Sharing Rule (ESR), which equally allocates the settlement revenues (or profits, or incoming flows) among the domestic carriers. The other one, the Proportional Return Rule (PRR), allocates the settlement revenue according to each carrier’s proportion of outgoing traffic, i.e., its domestic market share. A linear combination of the two simple division rules is indexed by \( \alpha \in [0, 1] \), with \( \alpha \) representing the portion of \( A \)'s incoming traffic that is subject to the PRR, and the remaining portion subject to the ESR. This specification is flexible in encompassing and comparing possible division rules. Without ambiguity, we use \( \alpha \) to represent the traffic division rule adopted for \( A \)'s carriers. Similarly, let \( \beta \in [0, 1] \) represent the portion of \( B \)'s incoming traffic that is subject to the PRR.

Given a pair of traffic division rules \((\alpha, \beta)\), the profit function of carrier \( i \) in \( A \) is

\[
\pi_{Ai} = (P_A(X) - c_A - s)x_i + \left[ \alpha \frac{x_i}{X} + (1 - \alpha) \frac{1}{m} \right] (r - d_A)Y, \tag{1}
\]

where \( x_i \) is the volume of outgoing calls initiated by carrier \( i \), \( X = \sum_{i=1}^{m} x_i \), and \((r - d_A)Y\) represents the total settlement profit to be divided among the \( m \) carriers. The first term in (1) is the retail profit collected from domestic customers, after paying \( s \) per minute to \( B \)'s carriers for their termination service. The second term is the proportion of the income from terminating \( B \)'s incoming traffic, based on a linear combination of the PRR and ESR. Thus, each carrier derives profit from two sources: call initiation (retail) and termination (wholesale) services.

Similarly, the profit function of carrier \( j \) in \( B \) is

\[
\pi_{Bj} = (P_B(Y) - c_B - r)y_j + \left[ \beta \frac{y_j}{Y} + (1 - \beta) \frac{1}{n} \right] (s - d_B)X, \tag{2}
\]

where \( y_j \) is the outgoing volume initiated by carrier \( j \), \( Y = \sum_{j=1}^{n} y_j \), and the total settlement profit from terminating \( A \)'s traffic, \((s - d_B)X\), is shared among \( n \) carriers according to a rule \( \beta \).

The total profits among carriers in each country can then be written as, respectively,

\[
\Pi_A = (P_A(X) - c_A - s)X + (r - d_A)Y \quad \text{and} \quad \Pi_B = (P_B(Y) - c_B - r)Y + (s - d_B)X. \tag{3}
\]

**Two benchmarks.** Before proceeding, we would like to state two familiar benchmarks. Under the demand and cost specifications in our model, the total marginal cost of providing a
The minute of call from A to B is \((c_A + d_B)\), and \((c_B + d_A)\) for the other calling direction. Social efficiency requires retail calling prices to be equal to the total marginal costs, i.e., \(P_A = c_A + d_B\) and \(P_B = c_B + d_A\). We refer to this set of prices as the **Social Efficiency Benchmark**.

At the other extreme, if international telephone services are provided by a single integrated carrier which controls telecommunications facilities in both countries (or if all the carriers from both countries behave collusively), the outcome is called the **Monopoly Benchmark**. The monopoly profit function from each direction of the traffic is denoted as \(M_A(X) = (P_A(X) - c_A - d_B)X\) and \(M_B(Y) = (P_B(Y) - c_B - d_A)Y\). By the Assumptions 1 and 2, the monopoly profit-maximizing traffic flows, denoted by \(X^M\) and \(Y^M\), are positive interior solutions. Let \(P^M_A = P_A(X^M)\) and \(P^M_B = P_B(Y^M)\). This monopoly outcome can be represented in terms of the familiar Lerner index,

\[
\frac{P^M_A - c_A - d_B}{P^M_A} = \frac{1}{\varepsilon_A(X^M)}, \quad \text{where} \quad \varepsilon_A(X) = -\frac{P_A}{P'_A X}.
\]

The expression for the market from B to A is similar.

### 3 Equilibrium Analysis

To determine the equilibrium outcome of the two-stage game set forth in the last section, we begin with a simpler case whereby both countries apply the ESR to divide the incoming traffic flows. This case can serve as a benchmark to help us better understand how the PRR affects the equilibrium outcome.

#### 3.1 Equal sharing rule

When both countries apply the ESR, i.e., \(\alpha = 0\) and \(\beta = 0\), the incoming traffic volumes are divided evenly among the carriers. Examining profit functions (1) and (2), we can easily see that the size of the foreign inflow has no effect on a carrier’s retail decision, implying that the decisions for the carriers in the same country in one stage are independent of their decisions in the other. In this case, our model of bilateral oligopoly essentially consists of two separate vertical structures, with each corresponding to a standard vertical structure in which a monopolistic upstream manufacturer supplies a product to downstream competing retailers.\(^{10}\)

We solve the game by backward induction. Given settlement rates \((r, s)\), the retail decision of a typical carrier \(i\) in A is to maximize its profits in (1) by choosing \(x_i\), and similarly for carrier \(j\) in B. Aggregating the Nash-Cournot equilibrium conditions for all carriers in A yields

\[
(P_A - c_A - s) + \frac{1}{m} P'_A X = 0,
\]

which implicitly determines the total outgoing volume \(X(s)\). In the first stage, the carriers in B jointly choose a settlement rate \(s\) to maximize their termination service profits \((s - d_B)X(s)\), which determines the equilibrium settlement rate \(s^*\), as well as the equilibrium total traffic volume \(X(s^*)\). Similar analysis applies to the other direction of the traffic flows.

\(^{10}\)For instance, in the market for phone calls from A to B, we can view carriers in A as downstream firms providing outgoing call retail services to their customers; and carriers in B as upstream firms jointly supplying termination services by charging settlement rate to A’s carriers.
For the purpose of characterizing the equilibrium outcome in the case of the PRR in the next subsection, we now introduce a new approach to determine the above subgame perfect equilibrium. From (5), we can express the total profits from termination services for carriers in $B$ (or the profit of the upstream monopolist in a standard vertical structure) as a function of the total traffic volume,

$$(s - d_B)X = (P_A - c_A - d_B)X + \frac{1}{m}P_A'X^2 \left[ \hat{=} \phi_A(X) \right], \quad (6)$$

where the right-hand-side is defined as function $\phi_A(X)$. Put another way, the upstream profit can be equivalently expressed as a function of the total downstream volume (without the choice variable $s$ explicitly in it). Note that the first term in $\phi_A(X)$ is the total profit as a function of the total traffic volume in the market for phone calls from $A$ to $B$, while $-\frac{1}{m}P_A'(X)X^2$ represents total retail profits for all carriers in $A$. Therefore, $\phi_A(X)$ represents the difference between the total profit and retail profit in the market from $A$ to $B$, which is the profit from termination services.

Similarly, country $B$’s retail equilibrium condition in the second stage of the game implicitly determines outgoing volume $Y(r)$, and the total settlement payment to carriers in $A$ can be written as

$$(r - d_A)Y = \phi_B(Y),$$

where

$$\phi_B(Y) = (P_B(Y) - c_B - d_A)Y + \frac{1}{n}P_B'(Y)Y^2. \quad (7)$$

From Assumption 1, both $X(s)$ and $Y(r)$ are strictly increasing. Therefore, we can equivalently represent settlement rate decisions as choosing incoming traffic volumes, i.e.,

$$\max_r (r - d_A)Y(r) \iff \max_Y \phi_B(Y) \quad \text{and} \quad \max_s (s - d_B)X(s) \iff \max_X \phi_A(X).$$

To facilitate our analysis, we make the following assumption.

**Assumption 3** Both $\phi_A(X)$ and $\phi_B(Y)$ are strictly concave in $X \in [0, \bar{X})$ and $Y \in [0, \bar{Y})$, respectively.

Assumption 3 imposes further restrictions on the curvatures of the demand functions. It is satisfied with common demand functions, such as linear, constant elasticity and exponential functions.

By the definitions of $\phi_A$ and $\phi_B$, as well as Assumption 2, it is easy to see that $\phi_A'(0) > 0$ and $\phi_B'(0) > 0$. Therefore, positive maximizers, denoted respectively by $X^*$ and $Y^*$, are determined by

$$\phi_A'(X^*) = 0, \quad \phi_B'(Y^*) = 0. \quad (8)$$

With $X^*$ and $Y^*$, we can then use (6) and (7) to determine equilibrium settlement rate $s^*$ and $r^*$, respectively.

Proposition 1 formally describes the equilibrium when both countries apply the ESR. The proof follows from the above discussion.

**Proposition 1** When both countries apply the ESR to divide the incoming traffic, there exists a unique subgame perfect equilibrium in which settlement rates $(r^*, s^*)$ are given by

$$r^* - d_A = \frac{\phi_B(Y^*)}{Y^*}, \quad \text{and} \quad s^* - d_B = \frac{\phi_A(X^*)}{X^*},$$

where $(X^*, Y^*)$ are given by (8). At these settlement rates, the equilibrium total volumes are equal to $X^*$ and $Y^*$, respectively.
Proposition 1 and the above analysis indicate that the equilibrium outcomes in the two countries’ markets are independent of each other. The equilibrium outcome under the ESR is the same as the one in a traditional model of upstream-downstream vertical structures. This separation property critically depends on the adoption of the ESR in both countries. In the next subsection, we will see that the adoption of the PRR makes the two vertical structures inter-dependent.

To discuss the equilibrium properties, we utilize the quantity elasticity of the slope of the inverse demand function, defined as

$$\eta_A(X) = \frac{P''_A X}{P'_A}.$$  

From (8), the equilibrium calling price, $$P^*_A = P_A(X^*)$$, can be shown as satisfying the following price-cost markup formula,

$$\frac{P^*_A - c_A - d_B}{P^*_A} = \frac{1}{\varepsilon_A(X^*)} \frac{m + 2 + \eta_A}{m}.$$  

By Assumption 2, $$\eta_A(X) > -2$$. Then, the right-hand-side of the above formula exceeds the inverse of the price elasticity of the demand, and hence, the equilibrium calling price exceeds the one in the Monopoly Benchmark.

Corollary 1 summarizes how the equilibrium outcome changes with respect to the degree of downstream competition.

**Corollary 1** *(The effects of domestic competition on the equilibrium outcome under ESR)*

(i) $$X^* (P^*_A)$$ increases (decreases) with $$m$$;

(ii) $$X^* < X^M (P^*_A > P^M_A)$$ and $$\lim_{m \to \infty} X^* = X^M (\lim_{m \to \infty} P^*_A = P^M_A)$$;

(iii) $$s^*X^*$$ increases with $$m$$ and

$$\text{sign} \left[ \frac{ds^*}{dm} \right] = \text{sign} \left[ \eta'_A(X^*) \right].$$  

Despite the separation property between the two markets, our approach here helps to generate some new insights that are not available in the literature on vertical structures. Corollary 1 illustrates an intuitive result that, in equilibrium, the total retail volume increases (and retail calling price decreases) with the degree of downstream competition, and hence, consumers benefit from an increased domestic retail competition. However, comparing the equilibrium outcome with the Monopoly Benchmark, we note that $$X^*$$ is always less than $$X^M (P^*_A$$ always exceeds $$P^M_A$$), and that, in the limit as $$m$$ goes to infinity, $$X^*$$ approaches $$X^M (\lim_{m \to \infty} P^*_A = P^M_A)$$. That is, even if the retail segment becomes perfectly competitive, the outcome can only be at the level of the Monopoly Benchmark. There is a limit in improving market efficiency by introducing competition in the retail segment if the termination services are still monopolized or collusively provided in the foreign country. The efficiency gain at the retail segment cannot offset the high markup at the other end of the market.

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11 This quantity elasticity describes the local curvature of the demand curve and has been widely used in the industrial organization literature. See, for example, Bresnahan and Reiss (1985), Farrell and Shapiro (1990), and Tyagi (1999).
How will the upstream input price (or settlement rate in our setting) respond to increased downstream competition? In a Stackelberg game, Tyagi (1999) shows that, if the quantity elasticity of slope of the inverse demand is constant (including linear demand and constant elasticity demand functions), the optimal input price of the monopolistic manufacturer is invariant to the number of its downstream retailers. Our results in Corollary 1 extend his finding. In particular, we find that the optimal response in input price (or settlement rate) by the upstream firm to the change in downstream competition is associated with the change of the quantity elasticity of slope of the inverse demand with respect to the volume change. For instance, if the quantity elasticity is decreasing in volumes as it is in the case of exponential demand functions, the optimal input price, $s^*$, falls as downstream competition increases. Nevertheless, Corollary 1 also shows that the total payouts from competitive downstream carriers to collusive upstream carriers (or monopolistic carrier), $s^*X^*$, always increase with the degree of downstream competition. When the downstream segment becomes more competitive, the optimal input price may fall, but the increased competition expands total volume at a faster speed, resulting in higher total payouts.

3.2 Proportional return rule

We now turn to equilibrium determination when the PRR is adopted. To facilitate our analysis of the effects of the PRR on the equilibrium outcome, we consider a linear combination of the ESR and PRR for each country, as described in section 2. Given a pair of incoming traffic division rules $\{\alpha, \beta\}$ and settlement rates $\{r, s\}$, the optimal decision on traffic volume by carrier $i$ in $A$ is determined by the first-order condition of (1),

$$\left(P_A - c_A - s\right) + P'_A x_i + \alpha \frac{X - x_i}{X^2} (r - d_A) Y = 0.$$  \hspace{1cm} (11)

There are similar first-order conditions for individual carriers in $B$. Denoting

$$\kappa_A = \frac{\alpha m - 1}{m}, \text{ and } \kappa_B = \frac{\beta n - 1}{n},$$  \hspace{1cm} (12)

we can express aggregate first-order conditions as

$$\phi_A(X) - (s - d_B)X + \kappa_A(r - d_A)Y = 0,$$  \hspace{1cm} (13)

$$\phi_B(Y) - (r - d_A)Y + \kappa_B(s - d_B)X = 0,$$  \hspace{1cm} (14)

where $\phi_A(X)$ and $\phi_B(Y)$ are defined in (6) and (7), respectively.

Fixing $s$ and $B$’s settlement payment $(r - d_A)Y$, under Assumptions 1 and 2, (13) uniquely determines the total retail volume $X$. A similar result holds for (14). Note that, from (13), $X$ is increasing in $\alpha$ and non-decreasing in $Y$. Under the PRR, a carrier’s share of the settlement revenue is determined by its retail market share $x_i/X$. The larger the settlement revenue, the more the carrier is willing to expand its traffic volume in order to capture a higher market share. Since the calling price $P_A$ is inversely related to the total outgoing volume $X$, the PRR exerts a downward pressure on the domestic calling price. Thus, consumers benefit from the application of the PRR, if settlement rates are fixed.

When determining the equilibrium settlement rates, we rule out unlikely cases where settlement rates are too low (below termination costs $d$) or too high (such that it is not possible to provide
the service for originating carriers). Define \( \bar{r} \) and \( \bar{s} \) to be the upper bounds of settlement rates such that
\[
\bar{s} = \lim_{X \to 0} \left[ P_A(X) + P_A'(X)X \right] - c_A, \quad \text{and} \quad \bar{r} = \lim_{Y \to 0} \left[ P_B(Y) + P_B'(Y)Y \right] - c_B.
\]
Under Assumption 2, \( d_A < \bar{r} \) and \( d_B < \bar{s} \). We restrict our attention to settlement rates in the ranges \( r \in [d_A, \bar{r}] \) and \( s \in [d_B, \bar{s}] \). Lemma 1 shows that (13) and (14) jointly determine a (unique) pair of positive \( (X,Y) \).

**Lemma 1** Suppose \( r \in [d_A, \bar{r}] \) and \( s \in [d_B, \bar{s}] \). Then (13) and (14) jointly determine a unique pair of strictly positive \( (X,Y) \).\(^\text{12}\)

What differs from the case of the ESR in section 3.1 is that the outgoing traffic volume \( X \) is a function of both \( s \) and \( r \) when \( \alpha > 0 \). This effect creates an interesting trade-off when choosing settlement rate \( r \): A larger settlement revenue decreases the retail profit because of more intense competition for incoming traffic. Carriers need to balance between the retail and settlement profits. The next two lemmas illustrate this trade-off and support a characterization of the equilibrium in Proposition 2.

We first explore the properties of \( X(r,s) \) and \( Y(r,s) \) in Lemma 2.

**Lemma 2** Given \((\kappa_A, \kappa_B)\), the following holds:

(i) \( X(r,s) \) is independent of \( r \) if \( \kappa_A = 0 \), and it is single-peaked in \( r \) if \( \kappa_A > 0 \).

(ii) \( Y(r,s) \) is independent of \( s \) if \( \kappa_B = 0 \), and it is single-peaked in \( s \) if \( \kappa_B > 0 \).

Denote the total settlement income in \( A \) as \( I_A(r,s) = (r - d_A)Y(r,s) \), \( B \)'s as \( I_B(r,s) = (s - d_B)X(r,s) \). In the first stage of the game, the choice of settlement rate \( r \) for \( B \)'s traffic is to maximize \( A \)'s total profits \( \Pi_A(r,s) = (P_A - c_A - s)X(r,s) + I_A(r,s) \); while \( s \) is chosen by \( B \)'s alliance to maximize \( \Pi_B(r,s) = (P_B - c_B - r)Y(r,s) + I_B(r,s) \).

**Lemma 3** Given \((\kappa_A, \kappa_B)\), the following holds:

(i) \( I_A(r,s) \) is single-peaked in \( r \), and \( \arg\max_r \Pi_A(r,s) = \arg\max_r I_A(r,s) \).

(ii) \( I_B(r,s) \) is single-peaked in \( s \), and \( \arg\max_s \Pi_B(r,s) = \arg\max_s I_B(r,s) \).

Lemma 3 points out that, in the first stage of the game, the maximization of industry profits in each country is equivalent to the maximization of settlement income. Each alliance is seemingly maximizing settlement income when choosing a settlement rate, without explicitly considering its impact on the domestic retail market. The reason can be explained as follows. As the settlement income increases, so does the total outgoing traffic volume, due to the PRR effect in the retail market, causing the total outflow traffic volume to divert even further from the monopoly retail level. The retail profit is therefore decreasing in settlement income, but it decreases at a rate slower than the increase of the rate of the settlement income. Let \( R_A(X) = (P_A(X) - c_A - s)X \) be the

\(^{12}\)There is a trivial solution to (13) and (14), i.e., \( \{X = 0, Y = 0\} \). However, by (11), the two traffic volumes cannot both be zero simultaneously. This trivial solution is due to our transformation of the FOCs.
retail profit of alliance A, and treat X as a function of $I_A$, $X(I_A)$. These results can be formally summarized as follows:

$$\frac{dR_A(X)}{dX} < 0, \quad \frac{dX}{dI_A} > 0, \quad \text{and} \quad \frac{dR_A(X)}{dX} \frac{dX}{dI_A} + 1 > 0.$$ 

Therefore, the trade-off between retail profit and settlement profit is dominated by the change in the settlement profit. Settlement rates are then chosen simultaneously by the two alliances in the first stage of the game to maximize their corresponding settlement profits. This outcome helps to derive the equilibrium of the two-stage game in Proposition 2.

**Proposition 2** Given a pair of traffic division rules $(\alpha, \beta)$, if the carriers within each country jointly set a settlement rate for carriers in the other country, and if the pair of settlement rates between the two countries are set non-cooperatively, then there exists a subgame perfect equilibrium in which settlement rates $(r^*, s^*)$ are given by

$$r^* - d_A = \frac{1}{(1 - \kappa_A \kappa_B) Y^*} [\kappa_B \phi_A(X^*) + \phi_B(Y^*)] \quad \text{and} \quad (15)$$

$$s^* - d_B = \frac{1}{(1 - \kappa_A \kappa_B) X^*} [\phi_A(X^*) + \kappa_A \phi_B(Y^*)], \quad (16)$$

where $(X^*, Y^*)$ are determined by (8). At these settlement rates, the equilibrium retail volumes are equal to $X^*$ and $Y^*$, respectively.

Given the characterization of the subgame perfect equilibrium in Proposition 2, we now discuss several important properties of this equilibrium. Since the comparative static results are symmetric between A and B, Corollaries 2 and 3 only present the results with a focus on country A. We are particularly interested in how traffic division rules and the degree of domestic competition affect the equilibrium outcomes. Let the total net settlement payment from carriers in A to carriers in B be

$$NP^* = s^* X^* - r^* Y^*.$$ 

From (3), the total profits for carriers in A can equivalently be expressed as

$$\Pi_A^* = (P_A^* - c_A) X^* - d_A Y^* - NP^*.$$ 

Corollary 2 states how the equilibrium outcome changes with respect to traffic division rules.

**Corollary 2** (The effects of traffic division rules)

(i) $(X^*, Y^*)$ is independent of $(\alpha, \beta)$;

(ii) $r^*$ always increases with $\beta$, increases with $\alpha$ if $\kappa_B > 0$, and is independent of $\alpha$ if $\kappa_B = 0$;

(iii) $s^*$ always increases with $\alpha$, increases with $\beta$ if $\kappa_A > 0$, and is independent of $\beta$ if $\kappa_A = 0$;

(iv) $NP^*$ increases with $\alpha$ and decreases with $\beta$; and

(v) $\Pi_A^*$ decreases with $\alpha$ and increases with $\beta$. 

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Surprisingly, we find that the application of the PRR in any country (as compared to the ESR) does not affect domestic and foreign traffic volumes (and hence, calling prices). This result can be understood as follows. The settlement payment from foreign carriers is part of the profit for which the domestic carriers compete. Since the carriers in each country form an alliance in choosing a settlement rate, such a rate becomes a tool to adjust the level of inflow traffic. For instance, we look at the optimal choice of \( r \) by carriers in \( A \). Lemma 3 shows that their best reply is characterized by the optimal level of settlement income \( I_A(r, s) \). Although the curvature of \( I_A(r, s) \) is affected by both \((\alpha, \beta)\) and \((m, n)\), its maximum level is always achieved when \( Y = Y^* \), an inflow level that is independent of the competition and demand conditions in \( A \), and is, instead, determined by the competition and demand conditions in \( B \). Thus, we can implicitly represent the best reply of the carriers in \( A \) as

\[
Y(r, s) = Y^*.
\]

It means that whatever the rate \( s \) is by the carriers in \( B \), the best interest of the alliance in \( A \) is to keep the level of inflow \( Y \) at \( Y^* \). Similarly, the best reply of the alliance in \( B \) in choosing settlement rate \( s \) is given by \( X(r, s) = X^* \). In equilibrium, the traffic volumes are kept at \((X^*, Y^*)\), and they are invariant to \((\alpha, \beta)\).

However, the equilibrium settlement rates are generally increasing in both \( \alpha \) and \( \beta \). Why does \( s^* \) increase with \( \alpha \)? Due to the PRR effect on retail competition, a larger \( \alpha \) induces a higher outflow from \( A \) to \( B \). If \( \kappa_B > 0 \), this larger traffic flow to \( B \) creates more intense competition among the carriers in the retail market in \( B \). In turn, the outflow \( Y \) from \( B \) to \( A \) increases if settlement rates do not adjust to the change of \( \alpha \). But as a whole, the carriers in \( A \) would like to keep this traffic volume at \( Y^* \), and the only way to do so is to choose a higher settlement rate \( r \) to restrict the retail competition among the carriers in \( B \). Thus, when \( \kappa_B > 0 \) (i.e., \( \beta > 0 \) and \( n > 1 \)), \( r^* \) increases with \( \alpha \), implying that the PRR induces a higher settlement rate (chosen by the foreign carriers) than the ESR does.

The settlement rate charged by foreign carriers, \( s^* \), increases with \( \alpha \) relatively faster than the rate charged by the domestic carriers, \( r^* \). Since the volumes in both directions are independent of \( \alpha \), the net settlement payment from carriers in \( A \) to carriers in \( B \) increases with \( \alpha \).

Furthermore, carriers in \( A \) jointly prefer the ESR over any linear combination of the ESR and PRR and the consumer surplus is invariant to traffic division rules. Thus the ESR Pareto-dominates any linear combination of the ESR and PRR by the standard of total surplus. The same results apply to \( B \). Thus, if each country (either the carrier alliance maximizes the industry profits or a government regulator maximizes the total surplus) is to choose a traffic division rule, the ESR is a dominant strategy. In an extended policy game where both countries choose between the ESR and PRR, \((\text{ESR}, \text{ESR})\) is a dominant strategy equilibrium.

Next, we turn to our discussion on how an increased domestic competition affects the equilibrium outcome. Since the the equilibrium traffic volumes and calling prices are independent of the traffic division rules, the comparative static results in Corollary 1 (i) and (ii) regarding the traffic volumes and calling prices hold when a linear combination of the ESR and PRR is adopted. In particular, the equilibrium outcome is less efficient than the Monopoly Benchmark, even if the retail market becomes increasingly competitive. As illustrated in Corollary 3 below, however, comparing with the ESR, the equilibrium settlement rates under the PRR may behave differently with respect to the degree of domestic competition.

**Corollary 3 (The effects of competition)**
\( (i) \frac{\partial r^*}{\partial m} > 0 \) if \( \kappa_B > 0 \), and \( \frac{\partial r^*}{\partial m} = 0 \) if \( \kappa_B = 0 \);
\( (ii) \frac{\partial s^*}{\partial m} > 0 \) if \( \eta_A'(X^*) \geq 0 \);
\( (iii) \frac{\partial (s^*X^*)}{\partial m} > 0 \) and \( \frac{\partial N P^*}{\partial m} > 0 \).

First, an increase in domestic competition \((m)\) in \( A \) induces more outflow to \( B \). If \( B \) with \( n > 1 \) applies the PRR (i.e., \( \kappa_B > 0 \)), competition among the carriers in \( B \) will, in turn, drive up its outflow to \( A \). Recall that the desirable level of inflow for carriers in \( A \) is \( Y^* \). In order to avoid exceeding this level, the best strategy is to increase the settlement rate charged on inflow to offset the PRR effect in \( B \). Therefore, in this case, \( r^* \) increases with \( m \).

Second, Corollary 1 (iii) implies that, in a traditional vertical structure, the upstream firm’s response in input price to a change in downstream competition is completely signed by the monotonicity of the quantity elasticity of the slope of the inverse demand curve. This result does not hold anymore when the PRR is introduced. Corollary 3 (ii) provides a sufficient condition under which the equilibrium input price (or settlement rate) charged to the domestic carriers, \( s^* \), increases with the degree of downstream competition \((m)\). When the quantity elasticity is monotonically decreasing, however, the equilibrium settlement rate is not necessarily monotonic in the number of downstream carriers, contrary to the prediction in the traditional vertical model (Corollary 1 [iii]).

Third, similar to the case of the ESR, despite that \( s^* \) may not always increase with \( m \), the total payouts from domestic carriers to foreign carriers, \( s^*X^* \), do increase with \( m \). Since \( r^* \) may increase with \( m \), the total receipts from foreign carriers, \( r^*Y^* \), may also increase with \( m \). Nevertheless, the payouts increase faster with \( m \) than the receipts, and hence, the net payments increase as the domestic competition goes up.

4 “Whipsawing” and Net Settlement Payments

Starting from MCI’s entrance in the late 1970s until the mid-1990s, the competitive U.S. carriers exchanged international traffic mainly with monopolistic carriers in most other countries. This asymmetric bilateral market structure caught particular attention at the FCC, and the agency believed that

...[I]n negotiating settlement rates, foreign monopoly carriers could pit competing U.S. carriers against one another, exploiting the fact that the U.S. carriers unwilling to pay settlement rates demanded by foreign carriers would lose business on those routes to higher-bidding U.S. competitors, as there are no alternative means of terminating international traffic. This practice, known as ‘whipsawing’, can drive up the cost to U.S. carriers of terminating international traffic to foreign markets, and hence, the prices paid by U.S. consumers. (FCC 1999)

The ISP was the agency’s first reaction toward the above concern. The policy required all U.S. carriers to de facto form an alliance in negotiating uniform settlement terms with foreign carriers.

\[13\text{We illustrate this outcome through a numerical example in which the demand functions are symmetric and exponential, } P_A = \exp(-\frac{1}{10}X), n = 3, \text{ and all marginal costs are zero. In this case, the settlement rate } s^* \text{ and the number of downstream carriers } (m) \text{ have an reversed U-shape relation: The rate increases when the number of carriers is small, and it decreases when the number is large.}\]
and divide incoming traffic by the PRR. What we analyzed in sections 2 and 3 is an approximation of this policy. To evaluate whether the policy was effective in lowering settlement rates, domestic consumer prices, and net settlement payments, we also need a characterization of the outcome when the U.S. carriers were whipsawed.

Maintaining the specifications of demands, costs and A’s retail competition as in section 2, we assume that B has only one carrier \( n = 1 \). In the first stage of the game, each of the A’s carriers individually sets a settlement rate \( r_i \) for the B’s carrier; B also chooses a separate rate \( s_i \) to each carrier in A. All rates are chosen simultaneously. In the second stage of the game, after observing settlement rates, carriers choose their outgoing traffic volumes.

For carrier \( i, i = 1, \ldots, m \), and for the carrier in B, respective profit functions are given by

\[
\pi_{Ai} = (P_A(X) - c_A - s_i)x_i + (r_i - d_A)y_i, \quad \text{and}
\]

\[
\Pi_B = \sum_{i=1}^{m} \left[ (P_B(Y) - c_B - r_i)y_i + (s_i - d_B)x_i \right].
\]

As before, the call-termination services offered by competing carriers in A are assumed to be homogeneous. This is plausible because this service is mainly an interconnection agreement between the long distance carriers and local networks within a country. The access to local networks is usually open to other carriers with regulated access charges. Therefore, we would expect the monopolistic carrier in B to extend its monopoly power and let competing carriers play a Bertrand type of game while choosing settlement terms. The equilibrium of this whipsawing game is given in Proposition 3.

**Proposition 3** Suppose \( m > 1, n = 1 \), and carriers in A individually set settlement rates with the carrier in B. There then exists a unique sub-game perfect equilibrium in which settlement rates \( (r_i, s_i) \) are given by

\[
\hat{r}_i = d_A, \quad \hat{s}_i = \phi_A(X^*)/X^* + d_B, \quad i = 1, \ldots, m,
\]

where \( X^* \) is determined by (8). At these settlement rates, the equilibrium volumes are equal to \( X^* \) and \( Y^M \), respectively.

Compared to the game in section 3, in the whipsawing game, both the monopolistic carrier and the consumers in B are better off, because \( Y^M > Y^* \) and \( \hat{r}_i < r_i \). As \( m \) increases, the equilibrium settlement rate \( \hat{s}_i \) in the whipsawing game changes analogously in the direction shown in Corollary 1. The equilibrium outflow from A is the same as the outcome in the previous section (Propositions 1 and 2), and the settlement rate paid by these carriers is equal to the one in Proposition 1. So the calling price and consumer surplus in A are not affected by a change in settlement determination regimes.

However, the settlement payments and profits of carriers differ across the two settlement regimes. In the game of whipsawing, the net settlement payment from A to B is

\[
NP^{W}(m, d_A) = \hat{s}X^* - d_AY^M = [\phi_A(X^*) + d_BX^*] - d_AY^M,
\]

which depends on the degree of competition \( (m) \) and the marginal cost of providing call-termination services \( (d_A) \) in A. Notice that the total payouts from carriers in A to the carrier in B, \( \hat{s}X^* \), are the same as they are in the model of settlement alliances with the ESR in section 2, and hence, Corollary 1 (iii) implies that the total payouts increase with \( m \). Since the total receipts for carriers
in A, \( d_A Y^M \), do not depend on \( m \), the net settlement payment from A to B, \( NP^W(m, d_A) \), increases with \( m \). Moreover, the total receipts depend on \( d_A \), while the total payouts do not. This suggests that, to avoid domestic carriers being whipsawed, and to reduce settlement deficits, the regulator may consider altering the level of \( d_A \) (part of this cost is access charge to local telephone networks); for instance, by choosing \( d_A \) to maximize \( d_A Y^M \).

In the game of settlement alliances with \( n = 1 \) and \( \alpha \) portion of the PRR in A, the net settlement payment is

\[
NP^{PRR}(\alpha, m, d_A) = \phi_A(X^*) + d_B X^* - [1 - \alpha(m - 1)/m] \phi_B(Y^*) - d_A Y^*.
\]

It depends on three possible policy instruments in A: division rule (\( \alpha \)), the degree of competition (\( m \)), and the marginal cost of providing call-termination services (\( d_A \)). The difference in the two net payments is

\[
\Delta(\alpha, m, d_A) = NP^{PRR}(\alpha, m) - NP^W(m) = d_A(Y^M - Y^*) - [1 - \alpha(m - 1)/m] \phi_B(Y^*).
\]

A regulatory policy imposing collusive determination of settlement rates with uniformity and PRR is effective in lowering net settlement payments if \( \Delta(\alpha, m, d_A) < 0 \). The policy effectiveness is not affected by the domestic demand condition; instead, three additional instruments, \( \alpha \), \( m \), and \( d_A \), can play important roles, which we discuss below.

First, the policy effectiveness critically depends on the size of \( d_A \). In the extreme but “unlikely” case, \( d_A = 0 \), the policy should always be effective. However, in practice, a major component of \( d_A \) is the (regulated) access charge to local telephone networks, which is often significant and makes \( \Delta(\alpha, m, d_A) \) positive. Thus, a relatively large access charge would contribute to the increased net settlement payments.

Second, the degree of domestic competition \( m \) affects \( \Delta(\alpha, m, d_A) \) only if there is an application of the PRR in the game of settlement alliances. When \( \alpha > 0 \) and \( m > 1 \), \( \Delta(\alpha, m, d_A) \) increases with \( \alpha \) and with \( m \), becoming positive when both \( \alpha \) and \( m \) are large. Indeed, \( \Delta(\alpha, m, d_A) \) increases with \( \alpha \), since \( NP^{PRR}(\alpha, m) \) does while \( NP^W(m) \) is independent of \( \alpha \). As \( m \) increases, if \( \alpha > 0 \), then \( NP^{PRR}(\alpha, m) \) increases faster than \( NP^W(m) \) does, and hence, the difference increases as well. Therefore, both the application of the PRR and an increased domestic competition make the settlement payment deficit worse. Our analysis suggests that, contrary to the FCC’s intention, the PRR might have been a crucial source of boosting net settlement payments from the U.S. to foreign countries; and moreover, domestic competition would weaken the effect of the attempted policy in reducing settlement deficits.

5 An Extension: Multiple Channels for International Traffic

The inefficient outcome found in section 3 is largely due to the market power generated by the bottleneck in terminating international calls. In this section, we extend our bilateral oligopoly model from sections 2 and 3 to allow for multiple channels for international calls across countries.

Suppose there are \( K \) international channels between the two countries. Each channel is technically capable of connecting a caller and receiver pair across countries, and any international call has to be transmitted through one of these channels. Each end of a channel is jointly owned by some of the carriers in that country. Thus, the carriers in each country are partitioned into \( K \)
non-overlapping groups. Let \( A \)’s partition be \( \{M_1, ..., M_K\} \), with \( m_k \) representing the number of members in group \( M_k \) and \( \sum_{k=1}^{K} m_k = m \). Symmetrically, let \( B \)’s partition be \( \{N_1, ..., N_K\} \), with \( n_k \) as the number of carriers in \( N_k \) and \( \sum_{k=1}^{K} n_k = n \). We assume that, for each \( k = 1, ..., K \), carriers in \( M_k \) and \( N_k \) together form channel \( k \) to exchange telephone traffic among themselves.

In the first stage of the game, for each \( k = 1, ..., K \), carriers in \( M_k \) jointly choose a settlement rate \( r_k \) for the traffic initiated by carriers in \( N_k \). All traffic volumes from \( N_k \) are terminated by \( M_k \) and the settlement payment is divided by group members according to a pre-determined division rule. Carriers in \( N_k \) choose a rate \( s_k \) for traffic initiated by \( M_k \) and the traffic and payment from \( M_k \) to \( N_k \) follows a similar structure. All settlement rates are chosen by groups simultaneously.

After the settlement rates are chosen, in the second stage of the game, carriers compete by setting their outgoing traffic volumes à la Cournot. That is, for \( k = 1, ..., K \), a carrier \( i \) in \( M_k \) (\( N_k \)) chooses its outgoing traffic volume \( x_{ik} \) (\( y_{ik} \)). Let \( X_k \) (\( Y_k \)) be the outgoing volume by group \( M_k \) (\( N_k \)), \( X_k = \sum_{i=1}^{m_k} x_{ik} \) and \( Y_k = \sum_{i=1}^{n_k} y_{ik} \). The total traffic volume in each market is \( X = \sum_{k=1}^{K} X_k \) and \( Y = \sum_{k=1}^{K} Y_k \), respectively.

Our analysis of multiple channels focuses on two situations where all groups apply the same rule to divide the incoming traffic, the ESR or the PRR. We then compare the equilibrium outcomes of the two situations with the outcomes in the previous sections to derive the implications of introducing competition at the termination service segment.

### 5.1 ESR in multiple channels

Suppose that the ESR is the only division rule applied by all carrier groups. The profit function of carrier \( i \) in group \( M_k \) is given by

\[
\pi_{Aki} = (P_A - c_A - s_k) x_{ki} + \frac{1}{m_k} (r_k - d_A) Y_k.
\]

The sub-game perfect equilibrium is characterized in Proposition 4.

**Proposition 4** Supposing that there are \( K \) international channels, and that each group of carriers applies the ESR, the equilibrium calling price in \( A \) is determined by

\[
\frac{P_A - c_A - d_B}{P_A} = \frac{1}{e_A} \frac{2(m + 1) - \sum_{k=1}^{K} \left(m_k \frac{X_k}{X}\right)}{m(m + 1) - \sum_{k=1}^{K} m_k^2 + \left[m - \sum_{k=1}^{K} \left(m_k \frac{X_k}{X}\right)\right]} \eta_A.
\]

The price in \( B \) is defined symmetrically.

The equilibrium price in one country is affected by the partition structure of its carriers, but not by the structure of carriers in the other country.

For the general partition structures, it is cumbersome to derive comparative statics and evaluate the impacts of competition. In what follows, we focus on a symmetric partition of carriers. Suppose that \( m \) and \( m_k = t \geq 1 \) are such that \( m = tK \), i.e., that each group has \( t \) carriers. At the symmetric equilibrium, \( \frac{X}{X_k} = \frac{1}{K} \). The price-cost markup (17) simply becomes

\[
\frac{P_A - c_A - d_B}{P_A} = \frac{1}{e_A} \frac{1}{m} \frac{2(m + 1) - \frac{m}{K}}{m + 1 - \frac{m}{K} + \left(1 - \frac{1}{K}\right) \eta_A}.
\]
The special case $K = 1$ is the result in (9). By the symmetric condition $s_k = s$, the equilibrium settlement rate $s$ charged by $B$ is,

$$\frac{s - dB}{PA} = \frac{1}{\varepsilon_A m} \frac{(m + 1) + \eta_A}{(m + 1) - \frac{m}{K} + (1 - \frac{1}{K}) \eta_A}.$$

Corollary 4 presents the properties of this symmetric equilibrium $(PA, s)$.

**Corollary 4** Suppose that $m = tK$, and that all groups apply the ESR. Then, at the sub-game perfect equilibrium the following holds:

(i) if $m$ is fixed, both $PA$ and $s$ decrease with $K$;

(ii) if $K$ is fixed, both $PA$ and $s$ decrease with $m$; and

(iii) if $K > 1$, $\lim_{m \to \infty} PA = c_A + dB$ and $\lim_{m \to \infty} s = dB$.

These results contrast sharply with the case of $K = 1$. In that case, the bilateral downstream competition can only reduce the horizontal externality caused by the imperfection in domestic retail competition, while the vertical externality remains. Until competition is also introduced into the settlement service market ($K > 1$), retail competition is able to drive the equilibrium calling prices toward the Social Efficiency Benchmark.

### 5.2 PRR in multiple channels

When the PRR is applied to allocate incoming traffic within some groups, the complexity of deriving the equilibrium grows substantially. Thus, we impose the following symmetric conditions to simplify our analysis.

1. The two countries are symmetric in demand and technology. The demand function in each country is linear, e.g., $PA = 1 - X$, $PB = 1 - Y$. Marginal costs are $c_A = c_B = c$, $d_A = d_B = d$.

2. There are two international telephone channels, $K = 2$.

3. The partition of carriers is symmetric, with $t$ members in each group, i.e., $m = n = 2t$.

This symmetric structure yields a symmetric equilibrium of the two-stage game. Let us examine the equilibrium outcome in $A$. Let $X$ be $A$’s total outgoing volume and $r$ be the settlement rate charged by each group in $A$. Denote $\tilde{X} = 1 - c - d$, which is the traffic level at the Social Efficiency Benchmark. The traffic initiated by each group is then $X/2$. In the symmetric equilibrium, $s = r$ and $Y = X$. Proposition 5 characterizes this symmetric equilibrium.

**Proposition 5** Suppose $K = 2$, the demands and costs are specified above, and all groups apply the PRR. There then exists a $\gamma \in \left[-\frac{3t+1}{t+1}, -2\right]$ such that the symmetric equilibrium is determined by

$$\frac{\tilde{X}}{X/2} = 2 - \frac{2t + \gamma}{t - 1}, \text{ and } \frac{r - d}{X/2} = -\frac{t + 1 + t\gamma}{t - 1}.$$

Furthermore, $\lim_{t \to \infty} \gamma = -3$, and $\lim_{t \to \infty} X = \tilde{X}$.

One implication of Proposition 5 is that, when the retail segment becomes perfectly competitive ($t \to \infty$), the equilibrium outcome is socially efficient, even if there are only two international channels. This is similar to the result when all groups use the ESR (Corollary 4).
Table 1: Comparison of Models (as $m \to \infty$)

<table>
<thead>
<tr>
<th>$K$</th>
<th>Model</th>
<th>$X/X$</th>
<th>$(r-d)/X$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ESR</td>
<td>$\frac{m}{2m+2} \to \frac{1}{2}$</td>
<td>$\frac{1}{2}$</td>
</tr>
<tr>
<td></td>
<td>PRR</td>
<td>$\frac{m}{2m+2} \to \frac{1}{2}$</td>
<td>$\frac{m}{2}$</td>
</tr>
<tr>
<td>2</td>
<td>ESR</td>
<td>$\frac{m(m+2)}{m^2+3m+4} \to 1$</td>
<td>$\frac{2}{m^2+3m+4} \to 0$, or $r \to d$</td>
</tr>
<tr>
<td></td>
<td>PRR</td>
<td>$\frac{m(m+2)}{m(m-2)} \to 1$</td>
<td>$\frac{1}{2}(-m^2+2m+4+2\gamma) \to 1$, or $r \to 1-c$</td>
</tr>
<tr>
<td>$m$</td>
<td>ESR</td>
<td>$\left(\frac{m}{m+1}\right)^2 \to 1$</td>
<td>$\frac{1}{m+1} \to 0$, or $r \to d$</td>
</tr>
</tbody>
</table>

5.3 Comparison

We provide two types of comparisons to understand the effects of multiple channels. First, we compare the equilibrium outcomes in the previous two subsections. Next, we compare the equilibrium for $K > 1$ with the one for $K = 1$ in an environment with symmetric linear demand, identical marginal cost, and symmetric carrier partitions, as assumed in subsection 5.2.

Notice that, under the same linear demand and cost structure and $K = 2$, when all four groups apply the ESR, the equilibrium outcome from (18) is given by

$$\left(\frac{\tilde{X}}{X}\right)^{ESR} = 1 + \frac{3t + 2}{2t^2 + 2t}.$$ 

Corollary 5 presents a comparison of the outcomes in these two scenarios.

**Corollary 5** Under the demand, cost, and carriers partition structure specified above, the equilibrium total traffic volume when all groups use the PRR exceeds the level when all use the ESR.

Recall that, when $K = 1$, the traffic division rule has no effect on equilibrium traffic volumes. Corollary 5 shows that, when multiple channels for traffic exchange are available, the PRR can increase the traffic volume as compared with the ESR, which benefits consumers and enhances social efficiency.

For the same specification of the demand and cost above, we now consider several cases of $K$: $K = 1$, $K = 2$, and $K = m = n$. The latter corresponds to a situation in which any international channel connects a single carrier in each country. For each of the cases, we compute the equilibrium volumes and settlement rates, as well as their limiting outcomes when the retail market is perfectly competitive, i.e., $m \to \infty$.

These outcomes are listed in Table 1. As in the last subsection, $\tilde{X}$ represents the efficient outcome $(1 - c - d)$ and $\gamma \in \left[-\frac{3m+2}{m+2}, -2\right]$. We use $X/\tilde{X}$ as a benchmark measure to compare traffic volumes and $(r-d)/\tilde{X}$ to compare settlement rates. In particular, $X/\tilde{X} = \frac{1}{2}$ corresponds to the Monopoly Benchmark, and $X/\tilde{X} = 1$ corresponds to the Social Efficiency Benchmark.

The efficiency of international telephone markets relies on two types of competition, retail (initiation service) competition and settlement (termination service) competition. The case $K = m$ generates the highest traffic volume among all five cases in Table 1. When the number of carriers is fixed, more international channels generate higher traffic volumes, resulting in higher efficiency gains.
Efficient traffic levels do not always come with cost-based settlement rates \((r = d)\). Specific traffic division rules also affect the level of settlement rates. Whenever the PRR is adopted in these cases, the settlement rates tend to be very high. However the traffic volumes are not reduced, due to the intensive retail competition under the PRR. This indicates that the level of settlement rates itself does not sufficiently reflect the efficiency of the internal telephone markets.

6 Empirical Evidence

In this section, we demonstrate that our major theoretical findings are consistent with the observed patterns in the U.S. market for international telephone services. An essential question is how market outcomes responded to increased competition and the FCC policies. First, we will summarize relevant facts that cover the changes in both bilateral market structures and the policies. Next, we quantitatively evaluate the impacts of changes in both domestic and foreign competition intensity as well as shifts in the FCC’s policies on the settlement rates and calling prices.

6.1 Factual evidence

Figure 1 shows average calling prices and settlement rates on all routes between the U.S. and foreign countries from 1964 to 2002. During this period, roughly 50% of the total revenues collected from domestic consumers were paid to foreign carriers for terminating calls. The sharp drop in calling prices in the late 1970s might be largely due to the entrance of MCI into this market, which had previously been monopolized by AT&T. One would also expect that the huge progress in telecommunications technology led to lower operating costs and might have benefited consumers through even lower calling rates.\(^{14}\) However, those pro-competitive factors seemed to not translate into large price drops until the mid-1990s, as shown in relatively stable average consumer calling prices between the mid-1980s and mid-1990s.\(^{15}\)

Figure 2 plots the total retail revenues, settlement payouts and receipts in year 2000 U.S. Dollar values from exchanging traffic with other countries. The gap between payouts and receipts is called net settlement payment, represented by the shaded area in the figure. For example, the U.S. net settlement payment to all other countries in 1996 was about \$6.4\ billion, 40% of the total billed revenue in that year.

From the trends shown in the above two figures and the FCC’s policy changes, we divide the development of the markets into four phases and use different models to analyze them.

**Phase I.** In the first phase, before the 1980s, the industry was typically a bilateral monopoly structure, where the U.S. market was solely operated by AT&T, and with other countries monopolized by single national carriers. The early literature has discussed this market structure, and it is nested in our model (by taking \(m = n = 1\)).

Our primary interest lies in the subsequent phases, when service competition appeared.

**Phase II.** We define the second phase as the period between MCI’s entrance in 1976 and the FCC’s implementation of its ISP in 1986. It started with a sharp drop in the U.S. calling prices and reduced markups between the prices and settlement rates, since the U.S. market was opened

\(^{14}\)For example, Cave and Donnelly (1996) provide the estimates of per minute cost of using trans-Atlantic cable, \$2.53 in 1956, \$0.04 in 1988, and \$0.02 in 1992.

\(^{15}\)We are aware of the fact that the average prices and settlement rates are also affected by the proportions of different U.S.-foreign routes in the total traffic volumes. However, we find that the calling prices and settlement rates at the major U.S.-foreign routes show similar trends as in Figure 1.
Figure 1: Average Calling Prices and Settlement Rates in the U.S. (1964–2002)

(a) MCI entered the long-distance telephone market in 1976.
(b) The U.S. FCC implemented the International Settlement Policy in 1986.
(c) The U.S. FCC implemented the Benchmark Policy in 1997.

Source: calculated from Blake and Lande (2004)

Figure 2: Billed Revenue, Settlement Payouts and Receipts in the U.S. (1964–2002)

Source: calculated from Blake and Lande (2004)
up for other entrants. The typical bilateral structure in this period was one in which the U.S. side was competitive and the other side monopolistic. We approximate this phase with a model of “whipsawing” in section 4.

Phase III. The decade between 1986 and 1997 is the third phase in our analysis. In this phase, the traffic exchange was subject to the requirements of uniform settlement rates and PRR on inbound traffic. Shown in Figure 1, Phase III, the U.S. callers did enjoy some but not substantial price drops during this period. On the other hand, in Figure 2, the increase of net settlement payments accelerated after the FCC rules were imposed, and this growing trend maintained throughout the phase.

We study this phase with a model of settlement alliances (section 3) and compare the equilibrium calling prices and net settlement payments between this game and the “whipsawing” one. We find that the equilibrium calling prices (or the outgoing traffic volumes \(X^*\)) are the same for the two games, which seems to be the situation around the phase-switching years in Figure 1. In addition, discussed in the end of section 4, the net settlement payments under settlement alliances could be higher than that under “whipsawing”, due to the significance of local access charge \((d_A)\) and the high degree of domestic competition \((m)\). This appears to be consistent with the observed pattern of net settlement payments around the time when ISP was imposed.

Our analysis of settlement alliances also suggests that net settlement payments increase as domestic competition intensifies. Using data from the website of the FCC International Bureau, we calculate market shares and \(HHI\)s of U.S. carriers and found that retail competition continued to increase over time as indicated by both decreasing pattern of \(HHI\)s and reducing market share of the largest carrier, AT&T.\(^{16}\) This pattern of increasing domestic competition and growing net settlement payments is consistent with our theoretical predictions. Henceforth, we argue that both the FCC enforcement of the PRR and the increase in U.S. domestic competition could have worsened the imbalance of settlement payments, opposite to the FCC’s primary intention of the policy.

Phase IV. To remedy the undesired market outcomes, the FCC further imposed settlement rate caps through its Benchmark Order in 1997. And since the late 1990s, many foreign countries initiated domestic competition, and the previously dominant carriers quickly lost their market shares. In response to the emerging competition in foreign countries, the FCC removed the all-inclusive collective bargaining requirement on the U.S. carriers, under the condition that the settlement rates were at or below the benchmark rates. Multiple channels for transmitting telephone messages became feasible. Since 1997, both the average settlement rates and calling prices fell significantly, as shown in Figure 1, and the previously growing trend of net settlement payments was reversed, as illustrated in Figure 2. Both the rate cap regulation and foreign competition seem to have contributed to those desirable market outcomes. The observed impact of the multiple-channel feature of the international telephone markets resulting from competition on both sides of the markets is consistent with our stylized theoretical analysis in section 5.

\(^{16}\)Information about market structure before 1992 is either unavailable or incomplete. However, one related characteristic of the period is certain. While the U.S. market has gradually been moving into a competitive structure since the late 1970s, with \(HHI\) and \(CR1\) in 1992 reaching 5,446 and 70.3, respectively, almost all of the other countries were still monopolistic. Our data shows that, in 1992, the \(HHI\)s of Australia, Chile, Korea, the Philippines, and the United Kingdom were 9,608, 6,801, 6,788, 8,920 and 6,436, respectively. All the other countries were monopolized.
6.2 Quantitative evidence

Data Construction. To econometrically evaluate the impact of bilateral market structures on major economic variables in the international telephone markets, we compiled the annual data on 47 countries\(^{17}\) that exchanged international traffic with the U.S. carriers, from the FCC’s International Bureau,\(^{18}\) and TeleGeography (1993–2005), for the period 1992–2004. It is an unbalanced panel because the foreign market information was unavailable for some years. All the monetary values are converted to the constant 2000 U.S. dollar by using the consumer price index.

In the following, we explain how the major variables are constructed. By the convention in panel analysis, subscript \(i\) denotes the country/route that interconnects with the U.S., and \(t\) the year.

1. **price and rate.** The calling prices and settlement rates to country \(i\) in year \(t\) are calculated by dividing the yearly amount collected from the U.S. callers and the yearly amount paid to the foreign carriers, respectively, by the total minutes delivered to the country.

2. **HHI.** The Herfindahl-Hirschman Index of the facility-based carriers at the U.S. side of the route \(i\) in year \(t\). The market share of each U.S. carrier is defined by its total outgoing minutes to the country \(i\) divided by the total minutes calling from all the U.S. facility-based carriers to \(i\) in the year \(t\).

3. **FMD.** This is an indicator if the largest foreign carrier on the route \(i\) had more than 50% market share in its country at year \(t\). We use this variable to proxy the foreign market structure, whether the foreign side of a route has market dominance. As we discussed in the Section 6.1, foreign market dominance (FMD) is a factor contributing to not only efficient multiple channels for routing traffic, but also whether the FCC considers to relax the ISP on that route.\(^{19}\)

4. **isr.** An indicator if the route \(i\) was granted International Simple Resale (isr) at the year \(t\). We use lower cases in abbreviating the policy to avoid confusion with the ISP. isr is a practice of routing international telephone traffic over private lines, especially among those new, non-facility-based international carriers, to completely bypass the traditional settlement rate system. The FCC authorized the isr on a country basis.\(^{20}\) Although it is outside the

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\(^{17}\)These countries, categorized by their geographic locations, are the followings: Africa: Egypt, and Nigeria; Asia-Pacific: Australia, China, Hong Kong, India, Indonesia, Japan, New Zealand, South Korea, Malaysia, Philippines, Singapore, Taiwan, and Thailand; Eastern Europe: Czech Republic and Hungary; Middle East: Israel; Western Hemisphere: Argentina, Brazil, Canada, Chile, Colombia, Dominican, Ecuador, Honduras, Mexico, and Peru; and Western Europe: Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, and the United Kingdom. They are all the countries where their historical market structure information is available to us.

\(^{18}\)See [http://www.fcc.gov/data/download-fcc-datasets](http://www.fcc.gov/data/download-fcc-datasets), Section 43.61 International Traffic Data. This contains the operational data for each U.S. carrier over the year.

\(^{19}\)Wright (1999) used a dummy, whether foreign market is monopolized or not, to proxy the foreign market structure. Madden and Savage (2000) used the total number of facility-based U.S. and foreign carriers on a route as the indicator of route competitiveness. As we argued above, non-monopoly is not a necessary condition for neither the relaxation of ISP by the FCC nor for multiple channels. In the examination of foreign markets, the FCC did consider the existence of market dominance. Since the exact rule of how the dominance was defined by the agency is unknown to us, we pick the market-share threshold of 50%. Though appearing to be \textit{ad hoc}, it is a reasonable choice, if not incorrect. Further, we also checked the threshold of 70%, and all of our results hold qualitatively.

\(^{20}\)Pearcy and Savage (2009) empirically studied the policy effect on calling prices in the U.S. They argued that the practice reduced the barrier to entry in the U.S. market and forced lower prices charged by the facility-based carriers.
Table 2: Summary Statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>s.d.</th>
<th>min.</th>
<th>max.</th>
<th>corr(x, price)</th>
<th>corr(x, rate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>price ($ per minute)</td>
<td>0.75</td>
<td>0.50</td>
<td>0.05</td>
<td>2.61</td>
<td>1.00</td>
<td>0.90</td>
</tr>
<tr>
<td>rate ($ per minute)</td>
<td>0.37</td>
<td>0.34</td>
<td>0.02</td>
<td>1.95</td>
<td>0.90</td>
<td>1.00</td>
</tr>
<tr>
<td>HHI</td>
<td>3157.64</td>
<td>1119.56</td>
<td>1395.68</td>
<td>6770.44</td>
<td>0.58</td>
<td>0.55</td>
</tr>
<tr>
<td>FMD</td>
<td>0.85</td>
<td>0.36</td>
<td>0</td>
<td>1</td>
<td>0.41</td>
<td>0.36</td>
</tr>
<tr>
<td>isr</td>
<td>0.39</td>
<td>0.49</td>
<td>0</td>
<td>1</td>
<td>-0.69</td>
<td>-0.66</td>
</tr>
</tbody>
</table>

All the monetary variables are in constant 2000 dollars.

settlement regimes among those facility-based carriers discussed in this paper, we wanted to include this policy variable given its likely impact.

Table 2 shows the summary statistics of major variables and their correlation coefficients with the calling prices and settlement rates in the pooled sample. Price and rate are highly correlated with coefficient 0.90. The sizable correlations of $HHI$ and $FMD$ with price and rate suggest the non-negligible influence of bilateral market structure on the U.S. market.

**Empirical Model and Estimation.** We intend to identify the impact of bilateral market structures on the settlement rates paid to foreign carriers, and the outgoing call prices in the U.S. The market structures are measured by the $HHI$ at the U.S. side and $FMD$ at the foreign side. We particularly want to capture the effect of the FCC’s policy change, especially its relaxation of ISP (including the PRR) since 1998. However, we do not observe which route was lifted from the ISP on which year. Given the fact that FCC required a ‘no market dominance’ condition at the foreign side for the relaxation, we can treat that dummy variable, $FMD$, as a proxy for potential policy change. Further, we interact the dummy with $HHI$ in the U.S. This would enable us to explore differential impacts of domestic carrier competition before and after the policy change.

We need to control the unobserved factors and possible correlations of those factors with the variables to our interests, as well as heterogeneity across countries. Both route and time fixed effects can control time-invariant route-specific and route-invariant time-specific unobserved heterogeneity. Within each route, there might be a route-specific time trend corresponding to (unobserved) changes in its demand and supply shifters, as noted in the data that both the outgoing call prices and the settlement rates in all international routes have shown downward trends to different magnitudes in our sample period.

To address these concerns, we adopt the “correlated random trend (CRT) model” (see Wooldridge (2005) and (2010, Section 11.2)), to control for route-specific linear trends in the outcomes. Specifically, we investigate the effects of bilateral market structures by the following model,

$$y_{it} = \beta_1 \log(HHI_{it}) + \beta_2 \log(HHI_{it}) \cdot FMD_{it} + \beta_3 FMD_{it} + X_i \gamma + c_i + \lambda_t + g_i t + u_{it}, \quad (19)$$

where $y_{it}$ represents the logarithm of outgoing call prices and settlement rates, respectively, for route $i$ in year $t$; $c_i$ is the set of route fixed effects, which controls for the mean differences in outcomes across routes; $\lambda_t$ is the set of year fixed effects that are common for all routes; $g_i$ is
the linear time trend specific for route $i$; $X_{it}$ is the set of time-varying controls; and, $u_{it}$ are idiosyncratic shocks in the outcomes and they are assumed to be independent across routes.

The model allows arbitrary correlation between $(c_i, g_i)$ and those market structure variables, as well as $X_{it}$. And, the time fixed-effects and the time trends together can better capture the appearance of Internet and other possible means of international communication, especially their differential effects across routes over time, than a model without the random trends.

After first-differencing the model (19), we get
\[
\Delta y_{it} = \beta_1 \Delta \log(HHI_{it}) + \beta_2 \Delta \log(HHI_{it}) \cdot FMD_{it} + \beta_3 \Delta FMD_{it} + \Delta X_{it} \gamma + g_i + \eta_t + \Delta u_{it},
\] (20)
where $\eta_t = \lambda_t - \lambda_{t-1}$ is a new set of time effects. We can thus apply a two-way fixed effects estimation to the model (20).

Our key interests lie in the parameters $\beta_1$ and $\beta_2$. $\beta_1$ alone represents the marginal effect of $HHI$, when there is no foreign dominance. $\beta_1 + \beta_2$ is the effect when foreign dominance is presented and henceforth the ISP enforced by the FCC. In the price regressions, as competition lowers prices and $HHI$ captures the opposite of competition, we expect $\beta_1$ and $\beta_1 + \beta_2$ to be positive. More importantly, our theory predicts that, when the ISP is enforced (due to the existence of foreign dominance), domestic competition would display weaker strengths in affecting the call prices, as compared to the scenario when multiple-channel is effective (due to non-existence of foreign dominance and relaxation of ISP). Therefore, we expect the sign of $\beta_2$, the coefficient for the interaction term of $HHI$ and $FMD$, to be negative.

For the settlement rate regressions, our theory suggests that, when multiple-channel is available, the marginal effect of $HHI$ can be negative or positive, depending on how the carrier group divides the incoming traffic (see Table 1, $K = 2$). When the ISP is enforced ($FMD = 1$), domestic competition tends to drive up the settlement rate (see Table 1, $K = 1$ with $PRR$). We hence expect the sign of $\beta_1 + \beta_2$ to be negative.

Given the fact that the market shares of the foreign dominant carriers in our data were their shares in all telecommunication services in those countries, we can safely believe that the variable $FMD$ is exogenous in our empirical models. However, to identify the interested parameters, we have to consider the possibility that $HHI$ is correlated with the error components. Both first-differencing and within-transformation are able to remove the bias due to $HHI$’s correlations with the market-specific, the time-specific disturbances, as well as the randomness in route-specific time trends. The remaining endogeneity due to $\text{cov}(\Delta \log(HHI_{it}), \Delta u_{it}) \neq 0$ and $\text{cov}(\Delta \log(HHI_{it}) \cdot FMD_{it}, \Delta u_{it}) \neq 0$ can be eliminated by applying the instrumental-variable method to within transformation of the model (20).

The set of IVs include the average $HHI$ and the average market share of the largest U.S. carrier ($CR_1$) in all other routes in the same year, as well as their interactions with $FMD$. Those two variables are commonly referred as Hausman IV. In our context of telecommunication markets, they are relevant IVs because a carrier’s entry would likely offer services in several routes together due to certain common unobserved factors, such as economy-of-scale in their business. Therefore, the $HHI$s in different routes may move in the same direction. The entry decision could also be affected by the dominance power in the market which is captured by the average $CR_1$. They are valid IVs because those common factors affecting entry/exit across routes would be unlikely

\footnote{There are no extra control variables in the settlement rate model. We include $\log(rate)$ in the call price equation, since the settlement rate is apparently an important factor affecting the prices.}
in the route-year-specific idiosyncratic shocks. The justification of IV choices is also statistically supported by the relevancy and validity tests.

For each of the outcome variables, we estimate the parameters by using the pooling model (by OLS), the CRT model, and the CRT with IV method. Robust standard errors clustered at the route level are used to account for heteroskedasticity and serial correlation within route.

**Empirical Results.** Table 3 presents the estimates from three specifications for each outcome variable. As we expected, the estimates for $\beta_1$ and $\beta_2$ display opposite signs among all the specifications in both the price and settlement rate regressions. The IV method for CRT model improves the estimates, and they are all significant at the 10% level. Since both Canada and Mexico are neighbors of the U.S., and those countries are clearly different to all other countries with respect to geography, cost, demand and institutions in our focus on the U.S. international telephone market, we also estimated those models with a sub-sample, excluding those two routes to test the robustness of our predictions, shown in Table 4.\(^{22}\) The estimates are qualitatively the same as their whole sample counterparts.

In the regressions of call prices, the parameters for $FMD$ are positive and significant in all models. An initial explanation would be that exchanging traffic with a concentrated foreign market would raise the U.S. caller’s prices. If we also treat this variable as a policy dummy, as we argued, the coefficient represents the mean difference in outgoing call prices for the routes subject to the ISP and the one lifted from it. However, since the relaxation of the ISP and foreign market decentralization usually came together, a careful explanation is that those two changes jointly contributed to the reduction in the U.S. prices.

The interaction term $HHI \ast FMD$ has negative coefficient, and its magnitude is less than the coefficient of $HHI$. That is, regardless of the foreign market structure, domestic competition tends to reduce the calling prices. Furthermore, when foreign dominance is presented, the competition effect is less than that without foreign dominance. This result is consistent with our theoretical comparison between the single-channel model and the multiple-channel one. Our theory suggests that if the carriers are subject to the ISP in determining settlement rates and dividing incoming traffic, the market competition would drive down the retail price to the Monopoly Benchmark at the most; if there are (effective) multiple channels available for call delivery, the competition could rapidly drive price down to its efficient level (see Table 1).

Nevertheless, the elasticity of prices to settlement rates are estimated to be 0.27 in the CRT models. Those estimates are comparable to the elasticity, 0.25 estimated in Madden and Savage (2000), whose sample period is 1991–1994. The slightly higher value could be reasonably due to the fact of intensified competition in our sample. This is another evidence for the robustness of our results.

In the regressions for settlement rates, one interesting finding is that all the estimates for $FMD$ are negative, and they are significant at 5% level except in the CRT. After controlling other variables, the route- and time-fixed effects, as well as the individual time trends, exchanging traffic with a concentrated foreign market would indeed help to reduce settlement rate.

The estimates of $\beta_1$ and $\beta_2$ have different patterns among the specifications. Since the IV method for CRT model is preferred over the other two in explaining the economics of the markets and identifying the coefficients, we shall take a close look at the IV result. In that, $\beta_1$ and $\beta_2$ have opposite signs. $\beta_1 < 0$ suggests that, when $FMD = 0$ (no foreign dominance), the competition among the U.S. carriers tends to raise up the settlement rate (which is one of our theoretical

\(^{22}\) We thank one referee for suggesting this robustness check.
predictions under the multiple-channel model, see Table 1, $K = 2$ with “PRR”). The existence of foreign dominance would place an opposing force toward the marginal effect of $HHI$ on settlement rates, fixing everything else. Their sum, $\beta_1 + \beta_2$ is close to zero and the hypothesis $\beta_1 + \beta_2 = 0$ cannot be rejected at common significance levels.

The effect of $isr$ is insignificant in all specifications for outgoing call prices. The estimates of $isr$ are all significantly negative among the three specifications for settlement rates. In the summary statistics (Table 2), $isr$ is negatively correlated with both price and rate with coefficients of $-0.69$ and $-0.66$, respectively. We hereby argue that the $isr$ is effectively a form of multiple channels for exchanging international traffic. Its direct effect is to force down the settlement rates and hence the calling prices, while its direct effects toward the facility-based carriers’ price competition is slim.

7 Concluding Remarks

This paper develops a game-theoretic model of two-way bilateral oligopoly to study the impact of competition and government regulatory policies on equilibrium calling prices, settlement rates, and net settlement payments in international telephone markets. We consider several policy structures describing how carriers on both sides are organized in determining settlement rates and exchanging telephone traffic. A particularly interesting policy is the requirement of a uniform settlement rate paid by domestic carriers, combined with the PRR to allocate inbound traffic. Our analysis suggests that competition and the PRR introduced in one country tend to increase net settlement payments to other countries, and that the overall market efficiency can be achieved only when multiple channels are available for international traffic exchanges.

We then analyze the evolution of bilateral market structure and regulatory policies, and explain the aggregate economic outcomes (i.e., the changes in settlement rates, calling prices and net settlement payments) through our theoretical models. Also, we utilize the correlated random trend model to explore the panel structure of the U.S. international telephone market data. We establish a relation between the bilateral market structure with the settlement rates and calling prices. The empirical findings are mostly robust and consistent with our major theoretical findings. The foreign dominance and ISP would alter the effects of domestic competition on both the settlement rates and calling prices. Particularly for calling prices, the marginal effect of domestic competition is weakened by a dominated structure in the foreign market.

We would like to discuss two related issues in our modeling approach. The first one is the mechanism for settlement rate determination among interconnecting carriers. There is no clear answer in the literature on network interconnections, where the attention is primarily on the relationship between access charge levels and downstream competition (see Armstrong (1998) and Laffont, Rey, and Tirole (1998a, 1998b)). Typical treatments include collusive determination, Nash bargaining, and non-cooperative games. Access to one’s network is complementary to the other, and their interconnection is an important tool to resolve network externalities. This feature supposedly calls for a cooperative approach in modeling settlement agreements among interconnecting carriers, e.g., collusive determination or a Nash bargaining solution. Collusive determination, however, involves side-payments, which are likely to be illegal, and its enforceability is always a question. Nash bargaining has its advantages. For example, a Nash bargaining solution does not have to involve side-payments among the bargaining parties, and all the parties are better off under the solution than status quo. But the drawbacks of this cooperative approach, including justifiable specification of bargaining powers and threat points, as well as the difficulty of deriving analytical solutions, lim-
its its applications. Given these considerations, in this paper, we have applied a non-cooperative approach toward the determination of settlement rates. We believe that our approach can help improve our understanding of the impacts of government policies on market outcomes.

The second issue is the reciprocity requirement in the International Settlement Policy, which simply requires a common settlement rate for calls in both directions. However, Figure 1 shows persistent gaps between the two settlement rates, paid and received by the U.S. carriers, over time. While this gap might be induced by statistical aggregations, it does not rule out the possibility that the reciprocity requirement was not followed in practice. On the other hand, the economic rationale behind reciprocity is unclear, since it does not respond to differential demand and cost structures across countries, and it is generally not in the interests of carriers to choose reciprocal rates (Cave and Donnelly 1996). Accordingly, we have not imposed the reciprocity requirement in our models. Armstrong (2002) discusses this reciprocity in a cooperative setting and shows that asymmetric countries will generally have divergent preferences over settlement rates. Our results in a non-cooperative and non-reciprocal setting provide a range for reciprocal settlement rates, if reciprocity is firmly required by the regulatory policy. It would therefore be interesting to formally model bargaining of settlement rates via a Nash bargaining approach and compare it with our approach.

The main economic factors studied in this paper are also present in several other industries including mobile communications, international postal services, and Internet. We expect that the insights from our study can help shed light toward better understanding of how market forces and regulatory policies work together in the development of those industries. Take Internet interconnection as an example. The Internet is an interconnected global network of computers and other mobile devices. In such a network, a number of core Internet Service Providers (ISPs) are interconnected to each other to provide routing capability for Internet end users; other ISPs (non-core ISPs), not connected to each other, purchase transit services from single or multiple core ISPs; end users purchase single or multiple connections to core or non-core ISPs. In the jargon of industrial organizations, core ISPs compete in the upstream market for backbone services while core and non-core ISPs generally compete in the downstream market for Internet services. However, since ISPs are located geographically in different regions, not all of them compete directly in the same retail market. Essentially, the set of core ISPs is partitioned into many subsets, with individual subset ISPs competing directly for retail customers, but not across. Non-core ISPs are partitioned similarly. In other words, the Internet can be viewed as a rich combination of mobile communications networks and international telephone networks, in which providers often have multiple sources of revenue in selling retail services, selling access to other networks, and paying other networks for their own access to the system. We can apply our framework of bilateral market structures and regulatory policies in this paper, combined with the literature on mobile communications, to study important economic issues such as Internet peering mechanisms (i.e., bill-and-keep) among core ISPs, second peering arrangements among non-core ISPs, multi-homing strategies by non-core ISPs and business users, and understand more generally the relationship between demand, cost structures, and market organizations.

\textsuperscript{23}For a discussion of the recent advances on Internet peering agreements, see Besen, Milgrom, Mitchell, and Srinagesh (2001).
Table 3: Calling prices and settlement rates

<table>
<thead>
<tr>
<th></th>
<th>log(price)</th>
<th></th>
<th>log(rate)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OLS CRT CRT-IV</td>
<td>OLS CRT CRT-IV</td>
<td>OLS CRT CRT-IV</td>
<td>OLS CRT CRT-IV</td>
</tr>
<tr>
<td>log(HHI)</td>
<td>0.94** 0.44** 0.47**</td>
<td>(0.11) (0.15) (0.13)</td>
<td>0.12 0.14 0.43**</td>
<td>(0.16) (0.10) (0.14)</td>
</tr>
<tr>
<td>log(HHI)*FMD</td>
<td>−0.73** −0.24* −0.29*</td>
<td>(0.13) (0.14) (0.15)</td>
<td>0.66** 0.03 0.40*</td>
<td>(0.17) (0.14) (0.20)</td>
</tr>
<tr>
<td>FMD</td>
<td>5.82** 1.86* 2.20*</td>
<td>(0.99) (1.05) (1.17)</td>
<td>−4.81** −0.36 −3.24**</td>
<td>(1.35) (1.06) (1.57)</td>
</tr>
<tr>
<td>isr</td>
<td>−0.02 −0.01 −0.01</td>
<td>(0.08) (0.05) (0.05)</td>
<td>−1.41** −0.19* −0.20*</td>
<td>(0.06) (0.05) (0.05)</td>
</tr>
<tr>
<td>log(rate)</td>
<td>0.62** 0.27** 0.27**</td>
<td>(0.04) (0.06) (0.06)</td>
<td>−2.34*</td>
<td></td>
</tr>
<tr>
<td>Const.</td>
<td>−7.15**</td>
<td>(1.22)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

First-stage F stat for log(HHI) | 255.52 (p=0.000) | 256.48 (p=0.000) |
First-stage F stat for log(HHI)*FMD | 42.62 (p=0.000) | 41.17 (p=0.000) |
Overidentification test (Hansen’s J) | 0.745 (p=0.689) | 1.206 (p=0.547) |
Obs. | 559 512 512 | 559 512 512 |

Note: **p < 0.05, *p < 0.1. OLS refers to pooling regressions. Both route and year fixed effects are included, as well as random time trends in CRT and CRT-IV models. In CRT-IV models, Δ log(HHI) and Δ log(HHI) * FMD are instrumented by Δ log(HHI) −1, Δ(CR1 −1), Δ log(HHI) −1 * FMD, and Δ(CR1 −1 * FMD), where HHI −1 is the average of HHI’s of all the routes except i in a year, and CR1 −1 is the average market share of the largest U.S. carriers in all the routes except i in a year. Robust standard errors in parentheses are adjusted for heteroskedasticity and serial correlation within route.
<table>
<thead>
<tr>
<th></th>
<th>log(price)</th>
<th>log(rate)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OLS</td>
<td>CRT</td>
</tr>
<tr>
<td>log(HHI)</td>
<td>0.99** (0.13)</td>
<td>0.48** (0.15)</td>
</tr>
<tr>
<td>log(HHI)*FMD</td>
<td>−0.74** (0.14)</td>
<td>−0.28** (0.14)</td>
</tr>
<tr>
<td>FMD</td>
<td>5.95** (1.11)</td>
<td>2.14** (1.07)</td>
</tr>
<tr>
<td>isr</td>
<td>−0.08 (0.07)</td>
<td>−0.00 (0.05)</td>
</tr>
<tr>
<td>log(rate)</td>
<td>0.59** (0.04)</td>
<td>0.27** (0.06)</td>
</tr>
<tr>
<td>Const.</td>
<td>−7.58** (1.01)</td>
<td></td>
</tr>
</tbody>
</table>

First-stage F stat for log(HHI) 383.06 (p=0.000) 379.14 (p=0.000)
First-stage F stat for log(HHI)*FMD 38.34 (p=0.000) 36.98 (p=0.000)
Overidentification test (Hansen’s J) 0.775 (p=0.679) 1.070 (p=0.586)

Obs. 533 488 488 533 488 488

Note: **p < 0.05, *p < 0.1. OLS refers to pooling regressions. Both route and year fixed effects are included, as well as random time trends in CRT and CRT-IV models. In CRT-IV models, Δlog(HHI<i>) and Δlog(HHI<i>)*FMD<i> are instrumented by Δlog(HHI−<i>), Δ(CR1−<i>), Δlog(HHI−<i>)*FMD<i>, and Δ(CR1−<i>)*FMD<i>), where HHI−<i> is the average of HHI’s of all the routes except i in a year, and CR1−<i> is the average market share of the largest U.S. carriers in all the routes except i in a year. Robust standard errors in parentheses are adjusted for heteroskedasticity and serial correlation within route.
Proof of Corollary 1. (i) By Assumption 1,
\[
\frac{\partial^2 \phi_A(X)}{\partial X \partial m} = -\frac{X}{m^2} (2P'_A + P''_AX) > 0.
\]
It follows from Assumption 3 that \(X^*\) increases with \(m\) and \(P'_A\) decreases with \(m\).

(ii) This can be easily obtained by comparing the first-order conditions that determine \(X^M\) and \(X^*\).

(iii) From Proposition 1, \(s^*X^* = \phi_A(X^*) + dBX^*\). By the envelope theorem,
\[
\frac{d\phi_A(X^*(m); m)}{dm} = -\frac{1}{m^2} P'_A(X^*)(X^*)^2 > 0
\]
and hence \(\phi_A(X^*)\) increases with \(m\). From (i), \(X^*\) increases with \(m\). It follows that \(s^*X^*\) increases with \(m\).

To determine the sign of \(ds^*/dm\), let \(\theta = 1/m\). From Proposition 1 and the definition of \(\phi_A(X^*)\) we can write
\[
s^* = s(X^*; \theta) = P_A(X^*) - c_A + \theta P'_A(X^*)X^*.
\]
Differentiating (21) with respect to \(\theta\) yields
\[
\begin{align*}
\frac{ds^*}{d\theta} &= \frac{\partial s^*}{\partial X} \frac{dX^*}{d\theta} + P'_AX^* = [(1 + \theta)P'_A + \theta P''_AX^*] \frac{dX^*}{d\theta} + P'_XX^* \\
&= \frac{\theta(P'_A(X^*))^2}{\phi''_A(X^*)} \frac{d\eta_A}{dX},
\end{align*}
\]
where the second equality follows from the fact that
\[
\frac{d\eta_A}{dX} = \frac{1}{(P'_A)^2} [P'_AP''_A + P'_AP'''_AX - (P''_A)^2X].
\]
Thus, from Assumption 3, \(d\eta_A/dX\) has the opposite sign of \(ds^*/d\theta\), or equivalently the same sign of \(ds^*/dm\).

Lemma A1 If (13) holds and \(s \in [d_B, \bar{s}]\), then \((s - d_B) - \phi'_A > (s - d_B) - \frac{\phi_A}{X} \geq 0\). If (14) holds and \(r \in [d_A, \bar{r}]\), then \((r - d_A) - \phi'_B > (r - d_A) - \frac{\phi_B}{Y} \geq 0\).

Proof. Notice that (13) is equivalent to,
\[
\frac{\phi_A}{X} - (s - d_B) + \kappa_A \frac{(r - d_A)Y}{X} = 0.
\]
The concavity of \(\phi_A\) by Assumption 3 together with \(\phi_A(0) = 0\) imply that \(\phi'_A < \frac{\phi_A}{X}\). It follows that
\[
-\phi'_A + (s - d_B) > -\frac{\phi_A}{X} + (s - d_B) = \kappa_A \frac{(r - d_A)Y}{X} \geq 0.
\]
The claim follows. The other inequalities follow from a similar argument.
Proof of Lemma 1. By definition, $0 \leq \kappa_A, \kappa_B < 1$. If $\kappa_A(r - d_A) = 0$, then there is a unique positive solution to (13), denoted as $X_0$, which is unaffected by $Y$. Similarly, we can find $Y_0$ by (14) when $\kappa_B(s - d_B) = 0$. Therefore, there is a unique pair of positive solutions $(X_0, Y_0)$ when $\kappa_A(r - d_A) = \kappa_B(s - d_B) = 0$.

When $\kappa_A(r - d_A) > 0$, (13) implies

$$Y = \frac{(s - d_B) X - \phi_A(X)}{\kappa_A(r - d_A)},$$

and then, applying Lemma A1,

$$\frac{dY}{dX} \bigg|_A = \frac{(s - d_B) - \phi_A'}{\kappa_A(r - d_A)} > 0, \quad \text{and} \quad \frac{d^2Y}{dX^2} \bigg|_A = \frac{-\phi_A''}{\kappa_A(r - d_A)} > 0. \quad (22)$$

Similarly, (14) and Lemma A1 imply that, if $\kappa_B(s - d_B) > 0$, then

$$\frac{dY}{dX} \bigg|_B = \frac{\kappa_B(s - d_B)}{(r - d_A) - \phi_B'} > 0, \quad \text{and} \quad \frac{d^2Y}{dX^2} \bigg|_B = \frac{-\phi_B''}{(\phi_B' - (r - d_A))} < 0. \quad (23)$$

Therefore, when $\kappa_A(r - d_A) > 0$ and $\kappa_B(s - d_B) > 0$, the aggregate best-reply curves $X(Y) \big|_A$ from (13) and $Y(X) \big|_B$ from (14) are both strictly concave in $(X > 0, Y > 0)$ space (or the former implies that $Y$ is strictly convex in $X$). Moreover, (13) also implies the best-reply curve goes through the point $(X_0, 0)$, and the curve by (14) goes through $(0, Y_0)$. Thus, the difference $Y(X) \big|_B - Y(X) \big|_A$ is concave in $X$, and $Y(X_0) \big|_B - Y(X_0) \big|_A > 0$. The claim follows if

$$\frac{dY}{dX} \bigg|_B < \frac{dY}{dX} \bigg|_A, \quad (24)$$

(or the difference is strictly decreasing in $X$). Indeed, multiplying the right-hand-side of (24) by $X/Y$ yields

$$\frac{dY}{dX} \bigg|_A \cdot \frac{X}{Y} = \frac{(s - d_B) - \phi_A'}{\kappa_A(r - d_A)} Y \bigg|_A X = \frac{(s - d_B) - \phi_A'}{(s - d_B) X - \phi_A X} \frac{(s - d_B) X - \phi_A X}{(s - d_B) - \phi_A X} > 1,$$

where the last inequality follows from Lemma A1. Similarly, multiplying the left-hand-side of (24) by $X/Y$ yields

$$\frac{dY}{dX} \bigg|_B \cdot \frac{X}{Y} < 1.$$

Hence, the claim in (24) follows.

Finally, suppose only one of $\kappa_A(r - d_A)$ and $\kappa_B(s - d_B)$ is positive, while the other is equal to zero. The proof is similar to the above argument, since one of the aggregate best-reply curves is a straight line. ■

Proof of Lemma 2. First, note that the comparative statics of $X(r, s)$ and $Y(r, s)$ are given by differentiating (13) and (14) with respect to $r$ and $s$,

$$\Gamma' \left( \frac{\partial X}{\partial r} \right) = \left( -\kappa_A Y \right), \Gamma' \left( \frac{\partial X}{\partial s} \right) = \left( \frac{X}{-\kappa_B X} \right), \quad (25)$$

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where
\[ \Gamma = \begin{pmatrix} \phi_A' - (s - d_B) & \kappa_A(r - d_A) \\ \kappa_B(s - d_B) & \phi_B' - (r - d_A) \end{pmatrix}. \]

The inequalities in Lemma A1, together with (13) and (14), imply \(|\Gamma| > 0\).

We only show part (i). Applying Cramer’s Rule in (25) yields
\[ \frac{\partial X}{\partial r} = -\frac{\kappa_A Y}{|\Gamma|} \phi_B'(Y). \tag{26} \]

Clearly, if \(\kappa_A = 0\), \(\frac{\partial X}{\partial r} = 0\). Next, consider \(\kappa_A > 0\). Applying Cramer’s Rule in (25) yields
\[ \frac{\partial Y}{\partial r} = \frac{\partial Y}{|\Gamma|} \left[ \phi_A' - (1 - \kappa_A \kappa_B)(s - d_B) \right] < \frac{\partial Y}{|\Gamma|} \left[ \frac{\phi_A}{X} - (1 - \kappa_A \kappa_B)(s - d_B) \right], \]

where the inequality follows from Assumption 3. Moreover, (13) and (14) imply
\[ \frac{\phi_A}{X} - (1 - \kappa_A \kappa_B)(s - d_B) = \frac{\kappa_A}{X} \left[ \kappa_B(s - d_B)X - (r - d_A)Y \right] = -\frac{\kappa_A}{X} \phi_B(Y). \]

Therefore,
\[ \frac{\partial Y}{\partial r} < -\frac{\kappa_A Y}{X|\Gamma|} \phi_B(Y). \tag{27} \]

Now, fixing \(s\) and \(Y = Y^*\) defined by \(\phi_B'(Y^*) = 0\), (13) and (14) jointly determine \(X(s)\) and \(r_0(s)\) as follows
\[ (r_0 - d_A)Y^* = \phi_B'(Y^*) + \kappa_B(s - d_B)X, \tag{28} \]

and
\[ \phi_A(X) - (1 - \kappa_A \kappa_B)(s - d_B)X + \kappa_A \phi_B(Y^*) = 0. \tag{29} \]

The left-hand-side of (29) is strictly concave in \(X\), positive at \(X = 0\) when \(\kappa_A > 0\), and negative when \(X\) is sufficiently large. Therefore, (29) determines a unique \(X(s)\), and henceforth, (28) determines uniquely \(r_0(s)\).

From (27), because \(\phi_B'(Y^*) > 0\), \(\frac{\partial Y}{\partial r} \bigg|_{r=r_0(s)} < 0\).

It follows from the uniqueness of \(r_0(s)\) that \(Y > Y^*\) and \(\phi_B'(Y) < 0\) when \(r < r_0(s)\) and that \(Y < Y^*\) and \(\phi_B'(Y) > 0\) when \(r > r_0(s)\). It therefore follows from (26) that \(\frac{\partial X}{\partial r} > 0\) when \(r < r_0(s)\) and \(\frac{\partial X}{\partial r} < 0\) when \(r > r_0(s)\). That is, \(X\) is single-peaked in \(r\). ■

**Proof of Lemma 3.** We only show part (i). If \(\kappa_A = 0\), the statement holds obviously. Let \(\kappa_A > 0\) and \(I_A = (r - d_A)Y\). From (26), we can compute
\[ \frac{\partial I_A}{\partial r} = \frac{Y}{|\Gamma|} \left[ \phi_A' - (s - d_B) \right] \phi_B'(Y) = \frac{[(s - d_B) - \phi_A'] \partial X}{\kappa_A} \frac{\partial X}{\partial r}. \tag{30} \]

By Lemma A1, \((s - d_B) - \phi_A' > 0\); hence, the sign of \(\frac{\partial I_A}{\partial r}\) is the same as the sign of \(\frac{\partial X}{\partial r}\). It then follows from Lemma 2 that \(I_A(r, s)\) is single-peaked in \(r\).
Next, define $R_A = (P_A - c_A - s)X$ and $M_A(X) = (P_A(X) - c_A - d_B)X$. Notice that $R_A = M_A - (s - d_B)X$, $\phi_A(X) = M_A(X) + \frac{1}{m} P_A X^2$, and

$$\phi'_A < M'_A.$$  

It follows that

$$\frac{dR_A}{dX} = M'_A - (s - d_B) > \phi'_A - (s - d_B).$$

From (13), we can express $X$ as a function of settlement income $I_A$ and settlement rate $s$. Moreover, when there is an infinitesimal change in $I_A$, (13) implies that

$$[\phi'_A - (s - d_B)] \frac{dX}{dI_A} + \kappa_A = 0,$$

or

$$\frac{dX}{dI_A} = \frac{-\kappa_A}{(s - d_B) - \phi'_A} > 0$$

due to Lemma A1.

Since $A'$s joint profit is $\Pi_A = R_A + I_A$, it follows that

$$\frac{\partial \Pi_A}{\partial I_A} = \frac{\partial R_A}{\partial X} \frac{\partial X}{\partial I_A} + 1 = 1 - \kappa_A > 0.$$ 

Since $I_A(r, s)$ is single-peaked in $r$, it follows that $\arg \max_r \Pi_A(r, s) = \arg \max_r I_A(r, s)$. The claim follows. 

**Proof of Proposition 2.** By Lemma 3 and (30), the best-reply by providers in $A$ in the first stage is to choose $r$ such that $\phi'_B(Y(r, s)) = 0$, or $Y(r, s) = Y^*$. Similarly, the best-reply by providers in $B$ is implicitly given by $X(r, s) = X^*$. Therefore, the equilibrium rates are jointly determined by $Y(r^*, s^*) = Y^*$ and $X(r^*, s^*) = X^*$. The equilibrium call volumes are then $X^*$ and $Y^*$ in $A$ and $B$, respectively. Finally, solving (13) and (14) simultaneously implies (15) and (16). 

**Proof of Corollary 2.** Parts $(i)$-$(iii)$ are direct consequences of Proposition 2. Part $(v)$ follows from $(i)$, $(iv)$ and the fact that $\Pi_A(\alpha, \beta) = (P_A^* - c_A)X^* - d_A Y^* - NP^*(\alpha, \beta)$. We now prove $(iv)$. From Proposition 2, $X^*$ and $Y^*$ are invariant to $\alpha$ and $\beta$. It follows from (15) and (16) that

$$\frac{\partial NP^*}{\partial \alpha} = \frac{(1 - \kappa_B) [\kappa_B \phi_A(X^*) + \phi_B(Y^*)]}{(1 - \kappa_A \kappa_B)^2} \cdot \frac{m - 1}{m} > 0;$$

$$\frac{\partial NP^*}{\partial \beta} = -\frac{(1 - \kappa_A) [\phi_A(X^*) + \kappa_A \phi_B(Y^*)]}{(1 - \kappa_A \kappa_B)^2} \cdot \frac{n - 1}{n} < 0.$$ 

The claim follows. 

**Proof of Corollary 3.** $(i)$ To show the sign of $\partial r^* / \partial m$, note that

$$(r - d_A)Y^* = \frac{\kappa_B \phi_A(X^*) + \phi_B(Y^*)}{1 - \kappa_B \kappa_B},$$

and $Y^*$ is independent of $m$. If $\kappa_B = 0$, $\partial r / \partial m = 0$ apparently. When $\kappa_B > 0$, $(1 - \kappa_B \kappa_B)$ is non-increasing in $m$. By the envelope theorem,

$$\frac{\partial \phi_A(X^*(m); m)}{\partial m} = \frac{\partial \phi_A(X^*, m)}{\partial m} |_{X = X^*} = -\frac{P_A'(X^*)^2}{m^2} > 0.$$ 

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Thus, $\partial r^*/\partial m > 0$. [(ii)] To show the sign of $\partial s^*/\partial m$, differentiate equation (16) by $m$,

$$\frac{\partial s^*}{\partial m} = \left( \frac{\phi_A}{X^*} + \frac{\phi_B}{X^*} \right) \frac{\partial}{\partial m} \left( \frac{1}{1 - \kappa_A \kappa_B} \right) + \frac{1}{1 - \kappa_A \kappa_B} \phi_B \frac{\partial}{\partial m} \left( \frac{\kappa_A \phi_B}{X^*} \right)$$

$$+ \frac{1}{1 - \kappa_A \kappa_B} \frac{\partial}{\partial m} \left( \frac{\phi_A}{X^*} \right).$$

(31)

The first term on the right-hand side of equation (31) is strictly positive. To obtain the sign of the second term, we will use the fact that $\phi''_A(X; m) = (2P'_A + P''_A X) + \frac{1}{m} (2P'_A + 4P''_A X + P'''_A X^2) < 0$. After combining common factors, we can derive

$$\frac{\partial}{\partial m} \left( \frac{\kappa_A \phi_B}{X^*} \right) = \frac{\alpha}{m^3 X \phi_A} [m \phi''_A - (m - 1)(2P'_A + P''_A X)].$$

And $m \phi''_A - (m - 1)(2P'_A + P''_A X) = (2P'_A + P''_A X) + (2P'_A + 4P''_A X + P'''_A X^2)$, which is $\phi''_A(X; m = 1)$, so it is negative. Thus, the second term of equation (31) is strictly positive, too.

Corollary 1 implies that if $\eta'_A(X^*) \geq 0$, $\frac{\partial}{\partial m} \left( \frac{\phi_A}{X^*} \right) \geq 0$. In sum, $\eta'_A(X^*) \geq 0$ is a sufficient condition for equation (31) to be positive.

[(iii)] The proof of $\partial(s^* X^*)/\partial m > 0$ is the same to that in Corollary 1. To show the second part, note that

$$N P^* = s^* X^* - r^* Y^*$$

$$= \left[ \frac{1 - \kappa_B}{1 - \kappa_A \kappa_B} \phi_A(X^*) + d_B X^* \right] - \left[ \frac{1 - \kappa_A}{1 - \kappa_A \kappa_B} \phi_B(Y^*) + d_A Y^* \right].$$

We know $X^*(m) = \arg \max_X \phi_A(X; m)$. By the envelope theorem,

$$\frac{d \phi_A(X^*(m); m)}{d m} = -\frac{1}{m^2} P'_A(X^*) (X^*)^2 > 0.$$

Also, $\frac{d X^*}{d m} > 0$ because the Assumption 1 gives

$$\frac{\partial^2 \phi_A(X)}{\partial X \partial m} = -\frac{X}{m^2} (2P'_A + P''_A X) > 0.$$

$Y^*$ is unaffected by $m$, so is $\phi_B(Y^*)$. Furthermore,

$$\frac{\partial \kappa_A}{\partial m} = \frac{\alpha}{m^2} > 0, \quad \frac{\partial}{\partial m} \left[ \frac{1 - \kappa_B}{1 - \kappa_A \kappa_B} \right] > 0, \quad \frac{\partial}{\partial m} \left[ \frac{1 - \kappa_A}{1 - \kappa_A \kappa_B} \right] < 0.$$

Combining the above conditions can imply that $\partial N P^* / \partial m > 0$. ■

**Proof of Proposition 3.** Since the termination services by all $A$’s carriers are homogeneous, $B$ can route all its traffic to carrier $A_i$, which charges the lowest rate, $r_i$. Thus, following the standard Bertrand argument, competition among $A$’s carriers over settlement income drives the equilibrium rate to be $r_i = r = d_A$. Thus, the traffic initiated by $B$ is $Y^M$. Carriers in $A$ terminate equal amount of traffic from $B$, i.e., $y_i = \frac{1}{m} Y^M$.

Given $s_i$, the volume initiated by $A_i$ is given by $\arg \max_{x_i} \pi_{A_i}$ and the first-order condition yields

$$P'_A x_i^2 + (P_A - c_A - d_B) x_i = (s_i - d_B) x_i.$$
The monotonicity between \( x_i \) and \( s_i \) lets us find out the optimal \( s_i \) by looking at \( x_i \), i.e.,

\[
\max_{s_i} \sum (s_i - d_B)x_i \Leftrightarrow \max_{x_i} \sum \left[ P'_A x_i^2 + (P_A - c_A - d_B)x_i \right].
\]

It is easy to show that the symmetric result \( s_i = s \) is optimal for \( B \). In the equilibrium, \( A \)'s traffic is given by \( \phi_A'(X^*) = 0 \), same as the volume found in Proposition 2. The rate \( s^* \) is given by \( s^* = d_B = \phi_A(X^*)/X^* \).

**Proof of Proposition 4.** We only show the equilibrium in \( A \). Given the partition structure and settlement rates determined in the first stage, the volumes \( X_k \) and \( X \) are given by

\[
\begin{align*}
P'_A X_k + m_k (P_A - c_A - s_k) &= 0; \quad (32) \\
P'_A X + m (P_A - c_A) - \sum_{k=1}^K m_k s_k &= 0.
\end{align*}
\]

The comparative statics with respect to \( s_k \) are

\[
\begin{align*}
\partial X_k / \partial s_k &= \frac{m_k}{(m+1) P'_A + P''_A X}; \\
\partial X / \partial s_B &= \frac{m_k (m+1-m_k) P'_A + P''_A (X - X_k)}{(m+1) P'_A + P''_A X}.
\end{align*}
\]

(33) and (34)

When \( N_k \) sets \( s_k \) for \( M_k \), the maximization of settlement revenue \( (s_k - d_B)X_k \) gives \( X_k + (s_k - d_B) \partial X_k / \partial s_B = 0 \).

\[
X_k + (s_k - d_B) \frac{m_k (m+1-m_k) P'_A + P''_A (X - X_k)}{(m+1) P'_A + P''_A X} = 0. \quad (35)
\]

Equation (32) also implies that \( P'_A X_k + m_k (P_A - c_A - d_B) = m_k (s_k - d_B) \). So, (35) becomes

\[
X_k + \frac{P'_A X_k + m_k (P_A - c_A - d_B)(m+1-m_k) P'_A + P''_A (X - X_k)}{(m+1) P'_A + P''_A X} = 0.
\]

The summation over \( k = 1, \ldots, K \) gives

\[
X + \sum_{k=1}^K \frac{P'_A X_k + m_k (P_A - c_A - d_B)(m+1-m_k) P'_A + P''_A (X - X_k)}{(m+1) P'_A + P''_A X} = 0.
\]

By the definition of \( \varepsilon_A \) and \( \eta_A \), we can transform it into the format of price-cost-markup.

**Proof of Corollary 4.** Rewrite the symmetric equilibrium condition in \( A \) as

\[
\begin{align*}
\frac{P_A - c_A - d_B}{P_A} &= \frac{1}{\varepsilon_A m} \frac{2(m+1) - \frac{m}{K} + (2 - \frac{1}{K}) \eta_A}{(m+1) - \frac{m}{K} + (1 - \frac{1}{K}) \eta_A}, \\
\frac{s - d_B}{P_A} &= \frac{1}{\varepsilon_A m} \frac{(m+1) + \eta_A}{(m+1) - \frac{m}{K} + (1 - \frac{1}{K}) \eta_A}.
\end{align*}
\]

36
Fix $m$ and let $K_1 < K_2$. Under the same $X$ (or $P_A$), we can find out that

$$\frac{2(m+1) - \frac{m}{K_1^2} + \left(2 - \frac{2}{K_1^2}\right)\eta_A}{(m+1) - \frac{m}{K_1^2} + \left(2 - \frac{1}{K_1^2}\right)\eta_A} > \frac{2(m+1) - \frac{m}{K_2^2} + \left(2 - \frac{2}{K_2^2}\right)\eta_A}{(m+1) - \frac{m}{K_2^2} + \left(2 - \frac{1}{K_2^2}\right)\eta_A}.$$  

Therefore, the equilibrium volume when $K = K_1$ must be lower than that under $K = K_2$, or the price is higher. By similar idea, we can show that $s$ is decreasing in $K$ and part (ii) of the corollary. The limiting result is obvious. ■

**Proof of Proposition 5.** Suppose all the groups apply the PRR. A carrier’s profit function is

$$\pi_{Aki} = (P_A - c_A - s_k) x_{ki} + \frac{x_{ki}}{X_k} (r_k - d_A) Y_k.$$  

Given the settlement rates for all groups, the traffic volume $X_k$ from group $M_k$ is given by

$$P'_A(X_k)^2 + m_k (P_A - c_A - s_k) X_k + (m_k - 1) (r_k - d_A) Y_k = 0, \tag{36}$$

and the total outgoing volume $X$ of country $A$ is given by

$$P'_AX + m (p^A - c^A - d^B) - \sum_k m_k (s_k - d_B) + \sum_k (m_k - 1) (r_k - d_A) \frac{Y_k}{X_k} = 0.$$  

By backward induction, at the rate-setting stage, group $k$ in $A$ chooses $r_k$ to maximize the joint profit of its members,

$$\pi_{Ak} = (P_A - c_A - s_k) X_k + (r_k - d_A) Y_k$$

$$= (P_A - c_A - s_k) X_k - \frac{1}{m_k - 1} \left[ P'_A(X_k)^2 + m_k (P_A - c_A - s_k) X_k \right]$$

$$= -\frac{1}{m_k - 1} \left[ (P_A - c_A - s_k) Y_k + P'_A(X_k)^2 \right],$$

where the second equality is derived from (36). The first-order condition is

$$P'_AX_k \left[ \frac{\partial X_k}{\partial r_k} + \frac{\partial X_{-k}}{\partial r_k} \right] + (P_A - c_A - s_k) \frac{\partial X_k}{\partial r_k}$$

$$+ P''_A(X_k)^2 \left[ \frac{\partial X_k}{\partial r_k} + \frac{\partial X_{-k}}{\partial r_k} \right] + 2P'_AX_k \frac{\partial X_k}{\partial r_k} = 0. \tag{37}$$

From (36), we define

$$(s_k - d_B) X_k = (P_A - c_A - d_B) X_k + \frac{1}{m_k} P'_A(X_k)^2 + \frac{m_k - 1}{m_k} (r_k - d_A) Y_k$$

$$\equiv f'_k(X_k, Y_k, X_{-k}, r_k),$$

where $X_{-k}$ refers to the total volume generated by the other group, $X_{-k} = X - X_k$. Similarly, we let $(r_k - d_A) Y_k = f''_k(X_k, Y_k, Y_{-k}, s_k).$
The comparative static properties of traffic volumes with respect to $r_k$ can be derived by using Cramer’s rule. Indeed, by imposing symmetry of the equilibrium conditions and letting $\beta = 1 - \left(\frac{3}{2} + \frac{1}{t}\right) X - c - r$, we have

$$
\Phi \begin{pmatrix} \frac{\partial X_k}{\partial r_k} \\ \frac{\partial Y_k}{\partial r_k} \\ \frac{\partial X_{-k}}{\partial r_k} \\ \frac{\partial Y_{-k}}{\partial r_k} \end{pmatrix} = \begin{pmatrix} -\frac{m_k - 1}{m_k} Y_k \\ Y_k \\ 0 \\ 0 \end{pmatrix},
$$

where

$$
\Phi = \begin{pmatrix} \frac{t-1}{t} (r - d) & \frac{t-1}{t} (r - d) & -X/2 & 0 \\ \beta & \beta & 0 & -X/2 \\ -X/2 & 0 & \beta & \frac{t-1}{t} (r - d) \\ 0 & -X/2 & \frac{t-1}{t} (r - d) & \beta \end{pmatrix},
$$

at the symmetric equilibrium, (36) becomes

$$
r - d = t \tilde{X} - \left( t + \frac{1}{t} \right) X,
$$

and

$$
\frac{\partial X_k}{\partial r_k} = C \left[ \left( \frac{t-1}{t} \right)^2 (r - d)^2 - \beta^2 \right] (\beta + r - d) + \left( \frac{Q}{2} \right)^2 (\beta - (r - d)),
$$

$$
\frac{\partial X_{-k}}{\partial r_k} = C \left( \frac{X}{2} \right) \left[ \left( \frac{X}{2} \right)^2 - \beta^2 - \left( \frac{t-1}{t} \right)^2 (r - d)^2 - 2\beta (r - d) \right],
$$

where $C$ is a common term of parameters. Moreover, at the symmetric equilibrium, (37) becomes

$$
\left[ \beta - \left( 1 - \frac{1}{t} \right) X \right] \frac{\partial X_k}{\partial r_k} - \frac{X}{2} \frac{\partial X_{-k}}{\partial r_k} = 0.
$$

Define $\gamma = 2\beta/Q$. By the definition of $\beta$ and (38), we find out that

$$
\frac{\tilde{X}}{X/2} = 2 - \frac{2/t + \gamma}{t - 1},
$$

$$
\frac{r - d}{X/2} = \frac{t + 1 + t\gamma}{t - 1}.
$$

Dividing (41) by $(X/2)^4$ and applying equations (39), (40), and (43) results in

$$
(2 + 5t - t^2 - 6t^3) + (-8t^3 + 9t^2 + 7t + 2) \gamma + t \left( 4t^2 + 4t + 5 \right) \gamma^2 + 2t^2 (t + 1) \gamma^3 = 0.
$$

This characterizes the symmetric equilibrium outcome in terms of $\gamma$, independent of the demand and cost parameters. There are three roots to (44), and Lemma A2 below points out the correct one for equilibrium, from which (42) gives us the diversion of equilibrium output from the social efficient level. This completes the proof. ■
Lemma A2  The first root of the equation (44) is within \([-\frac{3t+1}{t+1}, -2]\), the second is within \([-1,0]\), and the third is within \([0,2]\). The first root is the correct one for the symmetric equilibrium, and it approaches \(-3\) as \(t \to \infty\).

Proof. Evaluating (44) at \(\gamma = -\frac{3t+1}{t+1}\) gets

\[-t \left(2t^3 - 3t^2 + 1\right) \left(t + 1\right)^2 < 0.\]

and at \(\gamma = -2\), it is \(10t^3 - 19t^2 + 11t - 2 > 0\). Therefore, there is one root in \([-\frac{3t+1}{t+1}, -2]\). By a similar way, we can find out the regions within which the other two roots fall.

The non-negativity of price requires that \(\frac{X}{\hat{X}} > 1\), or \(\gamma < -\frac{2}{t} < 0\). Therefore the positive root is ruled out. The non-negativity of settlement rate requires \(\gamma < -\frac{t+1}{t} < -1\). So, only the root within \([-\frac{3t+1}{t+1}, -2]\) is the one for us. The limiting result is from dividing (44) by \(t^3\). ■

Proof of Corollary 5. Re-label the volume in (42) as \(\left(\frac{X}{\hat{X}}\right)^{PRR}\). The difference between equilibrium volumes under PRR and ESR is

\[
\Delta = \left(\frac{X}{\hat{X}}\right)^{PRR} - \left(\frac{X}{\hat{X}}\right)^{ESR} = \frac{2(t-1)}{2t-2} - \frac{2(t^2+t)}{2t^2+5t+2}
\]

\[
= -\frac{2t^2(3t + t\gamma + 1 + y)}{(-2t^2 + 2t + 2 + t\gamma)(3t + 2)}.
\]

Lemma A2 indicates that \((-2t^2 + 2t + 2 + t\gamma) < 0\) and \((3t + t\gamma + 1 + y) > 0\). Thus, \(\Delta > 0\). ■
References


