Exploring the Impact of Transmission Initiator Determination on Retail and Wholesale Markets

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Abstract— *This paper investigates the impact of the determination of the original initiator of a transmission on both customers and providers. The presented model, which performs inter-provider cost distribution based on the differentiated traffic flows was compared with the existing model, where intercarrier compensation is based on the net traffic flows. The studies consider markets with reciprocal and non-reciprocal access charges.*

Keywords: Interconnection, intercarrier compensation.

1. Introduction

The Internet is a system of interconnected networks, which are connected either through a direct link or an intermediate point, called Internet exchange point (IXP) to exchange traffic. Currently the Internet provides two basic types of interconnections such as peering and transit, and their variations [1-2]. Peering is the arrangement of traffic exchange on the free-settlement basis, called bill-and-keep (BAK), so that Internet service providers (ISPs) do not pay each other and derive revenues from their own customers. In the transit model, a customer ISP pays a transit ISP to deliver the traffic between the customers. The outcome of the negotiation process of being a transit or peered customer reflects on the assessment of the actual cost of traffic exchange [3-4]. According to the estimates in [5], 80% of the Internet traffic is routed via private peering. Emergence of new types of ISPs (with large number of customers and great amount of content) led to appearance of paid peering and partial transit.

Traditionally, before interconnecting, provider calculates whether the interconnection benefits would outweigh the costs [6]. Simple economic principle suggests sharing the costs between all parties. In the case of telephony, the study [7] argued that both calling and called parties benefit from the call, and consequently, should share the interconnection costs. In the Internet, under symmetry of traffic flows, the termination costs are set to zero, since it is assumed that the termination fees are roughly the same, and a peering arrangement is used. However, because no termination cost is charged, settlement-free model is considered inefficient in terms of cost compensation [8]. Generally, if providers are asymmetric in terms of size, peering is not appropriate, since providers incur different costs and benefit differently. In such a case, an interconnection arrangement is governed by the financial compensation in a bilaterally or unilaterally negotiated basis. In the bilateral settlement arrangements, the payments are based on the net traffic flow. In the unilateral settlement arrangements, a customer provider pays for sent and received traffic, even though traffic flows in both directions. This causes the existence of imbalance in allocation of the interconnection costs. In particular, smaller providers in high cost areas admit higher subscription fees. There exists a large body of literature that discusses interconnection challenges [6, 9-12]. Various pricing schemes have attempted to provide sustainable conditions for smaller ISPs [13-14]. These models make different trade-offs between the two objectives of interconnection pricing, viz., competition development and profitability. Hence, no single model has a clear advantage over the others. As cited in [5], it was recommended to establish bilateral settlement arrangements and to compensate each provider for the costs that it incurs in carrying traffic generated by the other network. However, it was argued that traffic flows are not a reasonable indicator to share the costs, since it is not clear who originally initiated a transmission and, therefore, who should pay for the costs. In other words, compensation between providers cannot be solely done based on the traffic flows, which provide a poor basis for cost sharing [5].

Recently provided analytical studies in [15-16], investigated the impact of the original initiator of a transmission at the wholesale market in the case of private peering and transit arrangements. Further, we provided preliminary results examining a retail market with reciprocal access charges [17]. However, the remaining literature on the economics of interconnection considers the intercarrier compensation based only on the flows of traffic [7, 18-21].

The main objective of this paper is to investigate the role of the determination of a transmission initiator on both retail and wholesale markets considering *private peering arrangements*. The paper differs from the prior reported studies in that it examines how beneficial is the traffic differentiation to *both customers and providers* and considers *elastic demand*. Our studies involve the earlier introduced model, called Differentiated Traffic-based Interconnection Agreement (DTIA) that distinguishes traffic into two types to determine a transmission initiator in the IP networks and to compensate the costs. In contrast to the existing solutions

[3], in which the payments are based on traffic flows, we compensate differently for a particular traffic type. Unlike telephony, where the transmission initiator covers the entire costs, the proposed model distributes the joint costs between all parties. Comparative studies were provided for the agreements based on the traffic flows (TF) and differentiated traffic flows compensations. We consider models with both symmetric and asymmetric access charges. The rest of the paper is organized as follows. Section 2 discusses existing financial settlements. Section 3 describes the motivation for traffic differentiation. Section 4 provides analytical studies. Section 5 concludes this paper.

2. Financial Settlements

Generally, providers arrange financial settlements in order to determine the distribution of the interconnection costs [3]. Before examining financial settlements within the Internet, we consider the telephone system. As an example, assume a scenario, where Alice makes a call to Bob. Accepting the call, Bob incurs termination costs to its provider that should be covered either directly by billing Bob or indirectly by billing the calling party's carrier. As cited in [8], "existing access charge rules and the majority of existing reciprocal compensation agreements require the calling party's carrier, [. . .], to compensate the called party's carrier for terminating the call". Thus, the initiator of the call, i.e., Alice pays to a subscribed provider for the entire call since Alice asked to reserve the circuit. In contrast to the telephony example, establishing a connection in the Internet does not require any reservation of a circuit. Usually packets between Alice and Bob are routed independently, sometimes even via different paths. Therefore, as cited in [22], "it is very important to distinguish between the *initiator* and the *sender*, and likewise between the *destination* and the *receiver*". The initiator is the party that initiates a call or a session, and the destination is the party that receives a call. In contrast, the sender (the originator) is the party that sends traffic, and the receiver (the terminator) is the party that receives traffic. In telephony, the initiator is considered to be the originator and is charged based on the transaction unit, namely a "call minute" for using the terminating network. Even though it may be argued that a TCP session can be considered as a call, where the initiator of a session pays for the entire traffic flow, such a model deals with technical issues, considerable costs, and implies uniform retail pricing. Currently the Internet uses the packet-based accounting model, under which the volume of the exchange traffic in both directions is measured, and adopts a small set of interconnection arrangements. Specifically, in the *service-provider* (unilateral) settlement, namely transit and paid peering business relationships, a customer ISP pays to a transit ISP for sent and received traffic. In the *settlement-free* agreement, namely peering relationships, providers do not pay each other. In some cases ISPs adopt the *negotiated-financial* (bilateral) settlement where the payments are based on the net flow of traffic. For discussions see [3, 22-23].

3. Motivation for Traffic Differentiation

The principle that we follow is that both parties derive benefits from the exchange of traffic and, therefore, should share the interconnection costs. Considering a system without externalities [24], the costs should be shared based on the benefits obtained by each party. However, in the real world, it is impossible to measure the benefits of parties and so to share the costs. If content is not equally distributed between providers, traffic imbalance occurs, and hence, costs and revenues are not shared evenly. As cited in [25], traffic flow is dominant towards a customer requested the content and generates 85% of the Internet traffic. This implies that inbound traffic is much more compared to outbound traffic of content request. In telephony for example, it is acceptable that more than 50% of rural network's revenue could come from the incoming calls. In contrast, in the Internet, customer networks pay for the entire traffic flows. It was recommended to compensate each provider for the costs that it incurs in carrying traffic based on the traffic flows. However, traffic flows are not a good measure for costs sharing, since "it is impossible to determine who originally initiated any given transmission on the Internet" and therefore, provide a poor basis for cost sharing [5]. On the other hand, providers are unwilling to inspect the IP header of a packet, since "the cost of carrying an individual packet is extremely small, and the cost of accounting for each packet may well be greater than the cost of carrying the packet across the providers" [23].

The DTIA model presented in [26] manages inter-provider cost compensation considering an original initiator of a transmission. In order to determine a party that originally initiated a transmission, we differentiated traffic into two types, referred to as *native*, which is originally initiated by the provider's own customers, and *stranger* that is originally initiated by the customers of any other network. Indeed, outgoing traffic of ISP$_i$ that is the same as adjacent provider's incoming traffic may be i) either a part of a transmission initiated by a customer of ISP$_i$, ii) or a part of a transmission initiated by a customer of any other network. Further, we suggest that providers compensate differently for a particular type of traffic, where stranger traffic is charged at a lower rate than native traffic. More specifically, each provider settled DTIA compensates the cost of carrying traffic according to the differentiated traffic flows. For detailed description of DTIA and its traffic management mechanism see [26].

4. The Model of Interconnection

Analytical studies are based on the bargaining process that is explored using Nash bargaining solution (NBS) which provides a fair and Pareto efficient outcome. This approach is taken in [20]. We begin by considering a market with non-reciprocal access charges, and continue by examining a case, where providers set reciprocal access rates. In our analysis we follow an assumption done in [18] to capture traffic imbalance and therefore, consider two types of the customers, namely websites (*which host information and content*) and consumers (*who use information and content provided on websites*). Actually, traffic is exchanged between consumers, between websites, from websites to consumers, and from consumers to websites. According to the proposed approach, a node (customer) in a P2P network is considered as *a consumer as well as a website simultaneously*, since it can act as a client and as a server. Thus, traffic generated from websites to consumers and vice versa along with Web, FTP and streaming media traffic captures P2P traffic. Traffic between consumers captures VoIP traffic that tends to be symmetric, and email exchange that is much smaller than traffic generated from websites to consumers. The studies investigate how *explicit monetary transfers* between providers depend on the differentiated traffic flows and focus on *traffic asymmetry* in its simplest way. Hence, they consider traffic exchange i) from consumers to websites, and ii) from websites to consumers. To simplify analytical studies the following assumptions were made in the paper:

Assumption 1: Let $\alpha_i \in (0,1)$ network *i*'s market share for consumers and $\beta_i \in (0,1)$ its market share for websites. The market consists of two providers $i \neq j = 1, 2$ and $\alpha_i + \alpha_j = \alpha$, $\beta_i + \beta_j = \beta$.

Assumption 2: For simplicity, a balanced calling pattern, where each consumer requests any website in any network with the same probability is considered.

Assumption 3: Each customer chooses only one provider to join, because of homogeneity of services. For simplicity, the number of consumers (websites) is normalized to one.

4.1 Demand Structure

We examine a scenario where ISP$_i$ has signed an interconnection agreement with ISP$_j$. Each customer derives utility from sending and receiving traffic. Let q_i be an individual demand, i.e., traffic volume originated by a particular customer. The marginal utility of consuming connection services is

$$u(q_i) = (\gamma - 0.5q_i)q_i \tag{1}$$

Given I income, a customer tries to solve the following problem subject to the budget constraint

$$\max_{q_i} \left[u(q_i) - p_i q_i\right] \quad \text{s.t. } p_i q_i + m \leq I \tag{2}$$

where p_i is a price for the consuming connection services and m denotes the consumption of all other goods. By solving the consumer surplus maximization problem, the level of traffic that optimizes customer's utility is

$$q_i(p_i) = \gamma - p_i \tag{3}$$

The indirect utility (i.e., the maximum utility with the current price and income) of a customer is calculated by substituting (3) in the maximization problem (2) and is given by

$$\upsilon(p_i) = \left(\gamma - \frac{\gamma - p_i}{2}\right)(\gamma - p_i) - p_i(\gamma - p_i) = \frac{(\gamma - p_i)^2}{2} \tag{4}$$

Let p_i^s and p_i^r ($\tilde{p}_i^s$ and $\tilde{p}_i^r$) be the network *i*'s prices that a subscribed consumer (website) pays for sending and receiving a unit of traffic respectively. Hence, the overall net utility derived by a consumer and a website of ISP$_i$ is defined as a function of the costs associated with originating and receiving traffic. It is calculated as follows

$$U_i = \left[u(q_i^s) - p_i^s q_i^s\right] + \left[u(\tilde{q}_j^s) - p_i^r \tilde{q}_j^s\right] \tag{5}$$

$$\tilde{U}_i = \left[u(\tilde{q}_i^s) - \tilde{p}_i^s \tilde{q}_i^s\right] + \left[u(q_j^s) - \tilde{p}_i^r q_j^s\right] \tag{6}$$

where q_i^s ($\tilde{q}_i^s$) is amount of traffic originated by a consumer (a website) of ISP$_i$. Given that each consumer of the network *i* initiates q_i requests, then the total amount of traffic originated by IPS$_i$ is $\alpha_i q_i$, where β_j proportion goes to ISP$_j$. Analogously, network *i*'s website originates $\tilde{q}_i$ traffic, and α_j proportion of it is terminated in ISP$_j$. As a result, the amount of native and stranger traffic from ISP$_i$ to ISP$_j$ is defined by

$$t_{ij}^{nat} = \alpha_i \beta_j q_i^s \qquad t_{ij}^{str} = \alpha_j \beta_i \tilde{q}_i^s \tag{7}$$

Similarly, q_j ($\tilde{q}_j$) traffic is generated by each consumer (website) of ISP$_j$, and the proportion β_i (α_i) is destined for the peered network. Thus, the amount of native and stranger traffic originating in ISP$_j$ and terminating in ISP$_i$ is

$$t_{ji}^{nat} = \alpha_j \beta_i q_j^s \qquad t_{ji}^{str} = \alpha_i \beta_j \tilde{q}_j^s \tag{8}$$

Summarizing, the total traffic volumes originated by the providers present the sum of native and stranger traffic volumes and are calculated as follows

$$t_{ij} = t_{ij}^{nat} + t_{ij}^{str} \qquad t_{ji} = t_{ji}^{nat} + t_{ji}^{str} \tag{9}$$

Because a *receiver pays principle* [27] is considered, q_i^s and $\tilde{q}_i^s$ depend not only on the price charged by the customer's provider, but also on the price that the rival network charges the receiver to terminate traffic. Consequently, at equilibrium the amount of traffic originated by a consumer and a website of ISP$_i$ and ready to be accepted in the peered network corresponds to the minimum level of communications

$$\begin{aligned} q_i^s &= min\left\{\gamma - p_i^s, \gamma - \tilde{p}_j^r\right\} \\ \tilde{q}_i^s &= min\left\{\gamma - \tilde{p}_i^s, \gamma - p_j^r\right\} \end{aligned} \tag{10}$$

The results may be summarized in the following way

$$q_i^s = \begin{cases} \gamma - p_i^s & \text{if } p_i^s \geq \tilde{p}_j^r \\ \gamma - \tilde{p}_j^r & \text{if } p_i^s \leq \tilde{p}_j^r \end{cases} \tag{11}$$

$$\tilde{q}_i^s = \begin{cases} \gamma - \tilde{p}_i^s & \text{if } \tilde{p}_i^s \geq p_j^r \\ \gamma - p_j^r & \text{if } \tilde{p}_i^s \leq p_j^r \end{cases} \tag{12}$$

Since providers are compensated when utilizing their infrastructures, we assume that prices for receiving traffic are lower then prices for sending traffic.

4.2 Non-reciprocal Access Charges

We start by examining a market with non-reciprocal access charges. Let network i's marginal costs of origination and termination be $c_i^o > 0$ and $c_i^t > 0$ respectively, where $c_i^o = c_i^t$. The marginal costs exhibit increasing returns to scale meaning that the incremental costs of a network increase as the network size decreases. For simplicity, the fixed network costs are normalized to zero. The access charges of ISPs for terminating native and stranger traffic are denoted by a_i and b_i respectively, where $a_i > b_i$. To carry out analysis, we assume that the network's access charge for terminating native traffic is set to the termination marginal cost, i.e., $a_i = c_i^t$, and for terminating stranger traffic is defined by $b_i = \varepsilon a_i$, where $0.5 \leq \varepsilon < 1$. To simplify studies we fix $\varepsilon = 0.5$, however, it is important to note, that the results are robust for the entire interval of ε. The model ignores on-net traffic, since it is focused on explicit monetary transfers between providers. The incremental profit that ISP$_i$ obtains from the interconnection is calculated as

$$\begin{aligned} \Pi_i = \alpha_i\beta_j(p_i^s - c_i^o - a_j)q_i^s + \alpha_j\beta_i(\tilde{p}_i^s - c_i^o - b_j)\tilde{q}_i^s \\ + \alpha_j\beta_i(\tilde{p}_i^r + a_i - c_i^t)q_j^s + \alpha_i\beta_j(p_i^r + b_i - c_i^t)\tilde{q}_j^s \end{aligned} \tag{13}$$

Retail prices

Consider the case when the providers act as monopolists. Therefore, each provider will choose level of the exchanged traffic that maximizes its profits. This demand has to be lower than, or equal to, a certain value and is given by

$$\begin{cases} \max\limits_{q_i^s} \Pi_i & \text{s.t } q_i^s \leq \gamma - \tilde{p}_j^r \\ \max\limits_{\tilde{q}_i^s} \Pi_i & \text{s.t } \tilde{q}_i^s \leq \gamma - p_j^r \end{cases} \tag{14}$$

From first order conditions for profit maximization follows

$$p_i^s = \begin{cases} \frac{\gamma + c_i^o + a}{2} & \text{if } \frac{\gamma + c_i^o + a}{2} \geq \tilde{p}_j^r \\ \tilde{p}_j^r & \text{if } \frac{\gamma + c_i^o + a}{2} \leq \tilde{p}_j^r \end{cases} \tag{15}$$

$$\tilde{p}_i^s = \begin{cases} \frac{\gamma + c_i^o + b}{2} & \text{if } \frac{\gamma + c_i^o + b}{2} \geq p_j^r \\ p_j^r & \text{if } \frac{\gamma + c_i^o + b}{2} \leq p_j^r \end{cases} \tag{16}$$

It is straightforward to show that the first-order conditions, which determine the prices for terminating traffic are equal to a perceived marginal cost, and thus, are defined as follows

$$\tilde{p}_i^r = c_i^t - a_i \tag{17}$$

$$p_i^r = c_i^t - b_i \tag{18}$$

The optimal demands can be calculated by replacing the obtained prices in (11) and (12). Retail revenues that ISP$_i$ obtaines from the subscribed consumers and websites are

$$\begin{aligned} \pi_i(p_i^s, p_i^r) = t_{ij}^{nat} p_i^s + t_{ji}^{str} p_i^r \\ \tilde{\pi}_i(\tilde{p}_i^s, \tilde{p}_i^r) = t_{ij}^{str} \tilde{p}_i^s + t_{ji}^{nat} \tilde{p}_i^r \end{aligned}$$

Substituting the optimal demands in (13), the profit function of ISP$_i$ can be rewritten as follows

$$\begin{aligned} \Pi_i = \alpha_i\beta_j(\gamma - p_i^s)(p_i^s - c_i^o - a_j) + \alpha_j\beta_i(\gamma - \tilde{p}_i^s)(\tilde{p}_i^s - c_i^o - b_j) \\ + \alpha_j\beta_i(\gamma - p_j^s)(\tilde{p}_i^r + a_i - c_i^t) + \alpha_i\beta_j(\gamma - \tilde{p}_j^s)(p_i^r + b_i - c_i^t) \end{aligned}$$

The outcome of the network according to the bargaining game (where providers equally split their payoffs) is

$$\Pi^{NBS} = 0.5(\Pi_i + \Pi_j)$$

If $\Pi_i > \Pi_j$, then ISP$_j$ receives the net interconnection payment from ISP$_i$ that is

$$\Pi^{NBS} - \Pi_j = 0.5\left(\Pi_i - \Pi_j\right) = \Delta\sigma \tag{19}$$

Replacing the obtained prices to the expression (19) the net interconnection charge can be rewritten as follows

$$\begin{aligned} 0.5(\Pi_i - \Pi_j) = 0.5\left[\alpha_i\beta_j\left(\frac{\gamma - c_i^o - a_j}{2}\right)^2 - \alpha_j\beta_i\left(\frac{\gamma - c_j^o - a_i}{2}\right)^2\right] \\ + 0.5\left[\alpha_j\beta_i\left(\frac{\gamma - c_i^o - b_j}{2}\right)^2 - \alpha_i\beta_j\left(\frac{\gamma - c_j^o - b_i}{2}\right)^2\right] \end{aligned}$$

In DTIA, the net interconnection payment is considered as two independent components i) one for a native traffic business, which is denoted by σ_{ij}^{nat}, and ii) another for a stranger traffic business that is denoted by σ_{ij}^{str}. Then

$$\sigma_{ij}^{nat} = 0.5\left[\alpha_i\beta_j\left(\tfrac{\gamma - c_i^o - a_j}{2}\right)^2 - \alpha_j\beta_i\left(\tfrac{\gamma - c_j^o - a_i}{2}\right)^2\right] \tag{20}$$

$$\sigma_{ij}^{str} = 0.5\left[\alpha_j\beta_i\left(\tfrac{\gamma - c_i^o - b_j}{2}\right)^2 - \alpha_i\beta_j\left(\tfrac{\gamma - c_j^o - b_i}{2}\right)^2\right] \tag{21}$$

The following analyses explore how the interconnection payments depend on the determination of a transmission initiator, considering all available cases of the market state in terms of providers' sizes (i.e. market shares).

Proposition 1: If $\alpha_i = \alpha_j$ and $\beta_i = \beta_j$, then the net interconnection payments between providers are zero.

Proof: Given that providers are symmetric in terms of size, then $c_i^t = c_j^t$ and access charges for native and stranger traffic flows are equal correspondingly. From (20) and (21), it is straightforward to show that $\sigma_{ij}^{nat} = \sigma_{ij}^{str} = 0$. ■

Proposition 2: If $\alpha_i = \alpha_j$ and $\beta_i > \beta_j$, then ISP$_i$ (ISP$_j$) subsidizes ISP$_j$ (ISP$_i$) for strange (native) traffic.

Proof: From the definition follows that $c_i^t < c_j^t$ and $\alpha_i\beta_j < \alpha_j\beta_i$.

Native: Considering (20), where $(\gamma - c_i^o - a_j) = (\gamma - c_j^o - a_i)$ follows that $\sigma_{ij}^{nat} < 0$. Here, ISP$_j$ subsidizes ISP$_i$.

Stranger: Given that $(\gamma - c_i^o - b_j) > (\gamma - c_j^o - b_i)$ and the business for stranger traffic (21), we obtain that $\sigma_{ij}^{str} > 0$. Thus, ISP$_j$ receives the payment from ISP$_i$. ■

Proposition 3: If $\beta_i = \beta_j$ and $\alpha_i > \alpha_j$, then ISP$_i$ subsidizes ISP$_j$ for native traffic.

Proof: Given that $\beta_i = \beta_j$ and $\alpha_i > \alpha_j$, then $c_i^t < c_j^t$ and $\alpha_i\beta_j > \alpha_j\beta_i$.

Native: From (20), we get that $\sigma_{ij}^{nat} > 0$. This implies that ISP$_i$ subsidizes ISP$_j$ for native traffic exchange.

Stranger: Considering the business for stranger traffic, (21) is not straightforward and is defined by

$$\sigma_{ij}^{str} \begin{cases} > 0 & \text{if } \alpha_j\beta_i/\alpha_i\beta_j > (\gamma - c_j^o - b_i)^2/(\gamma - c_i^o - b_j)^2 \\ = 0 & \text{if } \alpha_j\beta_i/\alpha_i\beta_j = (\gamma - c_j^o - b_i)^2/(\gamma - c_i^o - b_j)^2 \\ < 0 & \text{if } \alpha_j\beta_i/\alpha_i\beta_j < (\gamma - c_j^o - b_i)^2/(\gamma - c_i^o - b_j)^2 \end{cases} \tag{22}$$

where $(\gamma - c_i^o - b_j) \neq 0$. ■

When $\alpha_i > \alpha_j$ and $\beta_i > \beta_j$, the following cases for the traffic volumes are obtained from (9) 1) $t_{ij} > t_{ji}$, 2) $t_{ij} < t_{ji}$, and 3) $t_{ij} = t_{ji}$. The cases 1) and 2) are analogous to those described above. The last case is analyzed below.

Proposition 4: If $\alpha_i > \alpha_j$, $\beta_i > \beta_j$, and $t_{ij} = t_{ji}$, then $\alpha_i > \beta_i$ and $\beta_j > \alpha_j$.

Proof: The result is obtained from (20) and (21). ■

Proposition 5: If $\alpha_i > \alpha_j$, $\beta_i > \beta_j$, and $t_{ij} = t_{ji}$, then ISP$_i$ subsidizes ISP$_j$ for native traffic.

Proof: From the definition follows that $c_i^t < c_j^t$.
Native: Considering (20) and result of Proposition (4), it can be obtained that $\sigma_{ij}^{nat} > 0$. This implies that ISP$_j$ is subsidized by ISP$_i$.
Stranger: The component of stranger traffic (21) is not straightforward and is defined by (22). ■

Allowing that $\alpha_i > \alpha_j$ and $\beta_i < \beta_j$, the following cases for the termination costs are possible: 1) $c_i^t > c_j^t$, 2) $c_i^t < c_j^t$, and 3) $c_i^t = c_j^t$. The cases 1) and 2) are similar to those described above. The last case when the networks are equal in terms of size is examined below.

Proposition 6: If $\alpha_i > \alpha_j$, $\beta_i < \beta_j$, and $c_i^t = c_j^t$, then ISP$_i$ (ISP$_j$) subsidizes ISP$_j$ (ISP$_i$) for native (stranger) traffic.

Proof: Symmetry of networks in terms of size implies that $\beta_i = \alpha_j$.
Native: Considering the native traffic component (20), it can be obtained that $\sigma_{ij}^{nat} > 0$, therefore ISP$_i$ subsidizes ISP$_j$.
Stranger: From (21) follows that $\sigma_{ij}^{str} < 0$. In this case, ISP$_i$ receives the net payment from ISP$_j$. ■

4.3 Reciprocal Access Charges

In the following lines we examine a market with symmetric access rates, where the charge for terminating native traffic is set to the lowest termination marginal cost. Other parameters are defined analogously to the prior studies. The components for native and stranger traffic businesses are

$$\sigma_{ij}^{nat} = 0.5 \left[\alpha_i\beta_j \left(\frac{\gamma - c_i^o - a}{2} \right)^2 - \alpha_j\beta_i \left(\frac{\gamma - c_j^o - a}{2} \right)^2 \right] \tag{23}$$

$$\sigma_{ij}^{str} = 0.5 \left[\alpha_j\beta_i \left(\frac{\gamma - c_i^o - b}{2} \right)^2 - \alpha_i\beta_j \left(\frac{\gamma - c_j^o - b}{2} \right)^2 \right] \tag{24}$$

Analytical studies provided below consider all available market states in terms of providers' sizes.

Proposition 7: If $\alpha_i = \alpha_j$ and $\beta_i = \beta_j$, then the net interconnection payments between providers are zero.

Proof: From (23)-(24) follows that $\sigma_{ij}^{nat} = \sigma_{ij}^{str} = 0$. ■

Proposition 8: If $\alpha_i = \alpha_j$ and $\beta_i > \beta_j$, then ISP$_i$ subsidizes ISP$_j$ for stranger traffic.

Proof: If $\alpha_i = \alpha_j$ and $\beta_i > \beta_j$, then $c_i^t < c_j^t$, $\alpha_i\beta_j < \alpha_j\beta_i$ and $a = c_i^t$.
Native: Considering the native traffic business, where $(\gamma - c_i^o - a) > (\gamma - c_j^o - a)$, (23) is not straightforward

$$\sigma_{ij}^{nat} \begin{cases} > 0 & \text{if } \alpha_i\beta_j/\alpha_j\beta_i > (\gamma - c_j^o - a)^2/(\gamma - c_i^o - a)^2 \\ = 0 & \text{if } \alpha_i\beta_j/\alpha_j\beta_i = (\gamma - c_j^o - a)^2/(\gamma - c_i^o - a)^2 \\ < 0 & \text{if } \alpha_i\beta_j/\alpha_j\beta_i < (\gamma - c_j^o - a)^2/(\gamma - c_i^o - a)^2 \end{cases} \tag{25}$$

where $(\gamma - c_i^o - a) \neq 0$.
Stranger: Using (24), where $(\gamma - c_i^o - b) > (\gamma - c_j^o - b)$, the stranger traffic component is given by $\sigma_{ij}^{str} > 0$. In this case ISP$_j$ receives the net payment from ISP$_i$. ■

Proposition 9: If $\alpha_i > \alpha_j$ and $\beta_i = \beta_j$, then ISP$_i$ subsidizes ISP$_j$ for native traffic.

Proof: From the definition follows that $c_i^t < c_j^t$, $\alpha_i\beta_j > \alpha_j\beta_i$, and $a = c_i^t$.
Native: Considering (23), it can be obtained that $\sigma_{ij}^{nat} > 0$. Here, ISP$_i$ gets higher profit than ISP$_j$ from native traffic exchange and consequently, subsidizes the peered network.
Stranger: The expression for stranger traffic business (24) is not straightforward and is defined by

$$\sigma_{ij}^{str} \begin{cases} > 0 & \text{if } \alpha_j\beta_i/\alpha_i\beta_j > (\gamma - c_j^o - b)^2/(\gamma - c_i^o - b)^2 \\ = 0 & \text{if } \alpha_j\beta_i/\alpha_i\beta_j = (\gamma - c_j^o - b)^2/(\gamma - c_i^o - b)^2 \\ < 0 & \text{if } \alpha_j\beta_i/\alpha_i\beta_j < (\gamma - c_j^o - b)^2/(\gamma - c_i^o - b)^2 \end{cases} \tag{26}$$

where $(\gamma - c_i^o - b) \neq 0$. ■

Proposition 10: If $\alpha_i > \alpha_j$, $\beta_i > \beta_j$, and $t_{ij} = t_{ji}$, then ISP$_i$ subsidizes ISP$_j$ for native traffic.

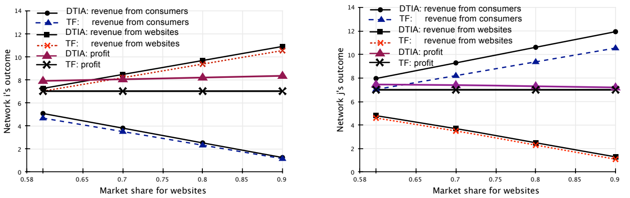
Proof: From the definition follows that $a = c_i^t$.
Native: Considering the expression (23), it can be obtained that $\sigma_{ij}^{nat} > 0$. Here, under symmetric traffic volumes, ISP$_i$ subsidizes ISP$_j$ for native traffic.
Stranger: The component for the stranger traffic business (24) is not straightforward and is defined by (26). ■

Assuming that $\alpha_i > \alpha_j$ and $\beta_i < \beta_j$, we investigate the case when providers' sizes are symmetric (i.e., $c_i^t = c_j^t$).

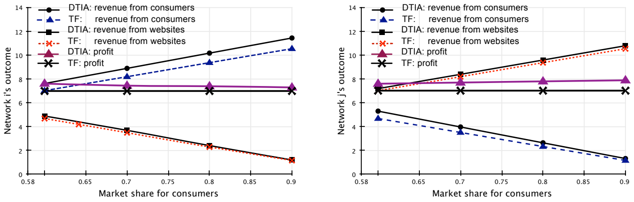
Proposition 11: If $\alpha_i > \alpha_j$, $\beta_i < \beta_j$, and $c_i^t = c_j^t$, then ISP$_i$ (ISP$_j$) subsidizes ISP$_j$ (ISP$_i$) for native (stranger) traffic.

Proof: Native: From (23) follows that ISP$_i$ subsidizes ISP$_j$.
Stranger: Using the expression for the stranger traffic business (24), it can be obtained that $\sigma_{ij}^{str} < 0$. ■

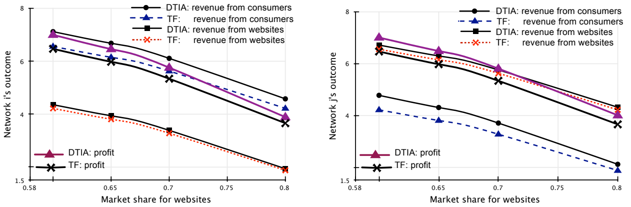
Fig. 1-2 and Tables 1-2 report the results of analytical studies, which examined the role of the transmission initiator on both customers and providers. Specifically, Fig. 1-2 show comparisons of providers' revenues and profits. The NBS outcomes and demand comparisons are presented in Tables 1-2. The models consider symmetric and asymmetric access charges. In order to enable us to calculate specific outcomes, the following values of termination costs were imposed: i)



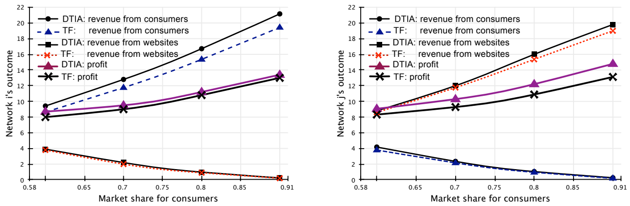
(a) $\alpha_i = \alpha_j$ and $\beta_i > \beta_j$



(b) $\alpha_i > \alpha_j$ and $\beta_i = \beta_j$



(c) $\alpha_i > \alpha_j$ and $\beta_i > \beta_j$



(d) $\alpha_i > \alpha_j$ and $\beta_i < \beta_j$

Fig. 1: Comparison of Providers' Outcomes (Non-reciprocal Access Charges).

$c_i^t = c_j^t = 1$ in cases I and V ii) $c_i^t = 1$, $c_j^t = 1.5$ in the other cases. The demand is given by $q_i(p_i) = 10 - p_i$. The parameters are chosen to be reasonable to consider all available market states in terms of provides' sizes. It is important to note, that even though the parameters are chosen arbitrarily, our conclusions do not depend on the chosen parameter values. The results obtained for a number of other values have not produced significant changes.

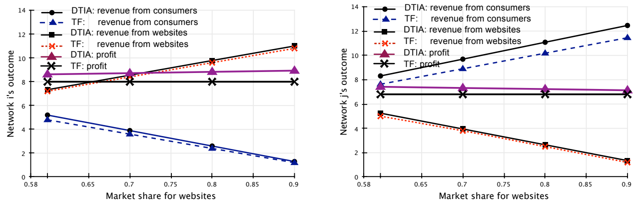
Table 1: Comparative Results of the DTIA and Net Traffic Flow Compensations (Non-reciprocal Access Charges).

	t_{ij}		t_{ji}		Π^{NBS}		$\Delta\sigma$	
	DTIA	**TF**	**DTIA**	**TF**	**DTIA**	**TF**	**DTIA**	**TF**
I	2.06	2.00	2.06	2.00	8.52	8.00	0.00	0.0
II	2.04	1.88	1.89	1.88	7.74	7.03	0.76	0.0
	2.03	1.88	1.90	1.88	7.72	7.03	0.64	0.0
	2.01	1.88	1.91	1.88	7.69	7.03	0.53	0.0
	1.99	1.88	1.93	1.88	7.67	7.03	0.42	0.0
III	1.89	1.88	1.99	1.88	7.54	7.03	-0.14	0.0
	1.91	1.88	1.98	1.88	7.57	7.03	-0.03	0.0
	1.93	1.88	1.96	1.88	7.59	7.03	0.09	0.0
	1.95	1.88	1.95	1.88	7.62	7.03	0.20	0.0
IV	1.01	0.98	1.02	0.98	3.95	3.66	0.05	0.0
	1.48	1.43	1.49	1.43	5.78	5.34	0.12	0.0
	1.65	1.59	1.66	1.59	6.47	5.98	0.15	0.0
	1.79	1.73	1.80	1.73	7.01	6.47	0.17	0.0
V	3.28	3.28	3.48	3.28	13.97	13.12	-0.83	0.0
	2.73	2.72	2.88	2.72	11.58	10.88	-0.62	0.0
	2.34	2.32	2.44	2.32	9.88	9.28	-0.41	0.0
	2.12	2.08	2.17	2.08	8.86	8.32	-0.21	0.0

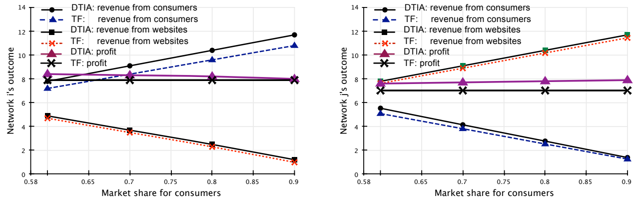
5. Discussions and Conclusions

In this paper we proposed models and their analysis, which are based on the DTIA strategy for intercarrier cost compensation. The purpose for this was to explore the effect of the determination of the transmission initiator on retail and wholesale markets with reciprocal and non-reciprocal access charges. In particular, the studies examined demand, interconnection payments, and providers' profits considering private peering. The results obtained from analytical studies (Fig. 1-2 and Tables 1-2) indicated that the traffic differentiation approach provides better results (in terms of demand and profits) than the classical solution for both models. From the comparison between DTIA and the agreement based on the net traffic flow compensation follows that the demand (the amount of traffic originated by the providers) is increased. More specifically, DTIA leads to the increase of the traffic volume originated in one network and ready to be terminated in the peered network. Traffic level originated by any customer depends also on another party which is accepting incoming traffic, and therefore, corresponds to the minimum level that one would like to originate and another would like to accept. In the proposed agreement the prices obtained for stranger traffic are lower than these prices in the classical model. This is due to the main concept of our strategy, where providers distinguish traffic and compensate the cost for carrying stranger traffic partially.

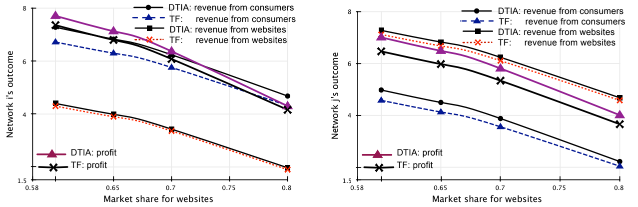
From economics, it is known that the relationship between price and demand is an inverse relationship. This means that the decrease in prices leads to the increase in demand. Obviously, revenues of providers are also increased. Specifically, retail revenues obtained from consumers and websites are higher in DTIA than in the classical model. Finally, the determination of the transmission initiator induces providers to receive higher profits and increases providers' outcome according to NBS (Tables 1-2). Resuming, DTIA is beneficial for both customers and providers.



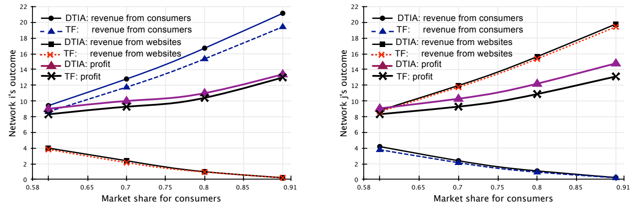
(a) $\alpha_i = \alpha_j$ and $\beta_i > \beta_j$



(b) $\alpha_i > \alpha_j$ and $\beta_i = \beta_j$



(c) $\alpha_i > \alpha_j$ and $\beta_i > \beta_j$



(d) $\alpha_i > \alpha_j$ and $\beta_i < \beta_j$

Fig. 2: Comparison of Providers' Outcomes (Reciprocal Access Charges).

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Table 2: Comparative Results of the DTIA and Net Traffic Flow Compensations (Reciprocal Access Charges).

	t_{ij}		t_{ji}		Π^{NBS}		$\Delta\sigma$	
	DTIA	**TF**	**DTIA**	**TF**	**DTIA**	**TF**	**DTIA**	**TF**
I	2.06	2.00	2.06	2.00	8.52	8.00	0.0	0.0
II	2.11	2.00	1.89	1.88	8.03	7.52	0.90	0.48
	2.10	2.00	1.90	1.88	8.03	7.52	0.80	0.48
	2.09	2.00	1.91	1.88	8.02	7.52	0.70	0.48
	2.08	2.00	1.93	1.88	8.02	7.52	0.60	0.48
III	2.01	2.00	1.99	1.88	8.00	7.52	0.10	0.48
	2.03	2.00	1.98	1.88	8.01	7.52	0.20	0.48
	2.04	2.00	1.96	1.88	8.01	7.52	0.30	0.48
	2.05	2.00	1.95	1.88	8.01	7.52	0.40	0.48
IV	1.06	1.04	1.02	0.98	4.17	3.91	0.16	0.25
	1.56	1.52	1.49	1.43	6.09	5.71	0.28	0.37
	1.74	1.70	1.66	1.59	6.81	6.39	0.33	0.41
	1.89	1.84	1.80	1.73	7.37	6.91	0.36	0.45
V	3.28	3.28	3.48	3.28	13.97	13.12	-0.83	0.0
	2.73	2.72	2.88	2.72	11.58	10.88	-0.62	0.0
	2.34	2.32	2.44	2.32	9.88	9.28	-0.41	0.0
	2.12	2.08	2.17	2.08	8.86	8.32	-0.21	0.0