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Net Neutrality under Usage-Based Pricing: a Game-Theoretic Analysis with User Loyalty

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Abstract

Network neutrality issue has been recently received a great attention from the research community, the industry and the network regulators alike. From the European perspectives, the net neutrality issue is increasingly important because it is also part of the Digital Agenda 2020 recently approved by the European Commission [1, 2]. Until now, usage-based pricing and network neutrality have been considered as two different research problems and very few network neutrality researchers examine usage-based pricing as a main consideration. In addition, the user behaviour such as user loyalty issue should be seriously taken into consideration because users will have an increasingly more important role in the operation and management of the network. In this paper, we address the net neutrality issue by investigating the usage-based pricing in presence of user loyalty from the game-theoretic perspective. The contributions of the paper are twofold. First, we provide game-theoretic models for the interaction among the stakeholders under usage-based pricing under the presence of customer loyalty. Based on the models, we compute the Nash equilibrium prices of the pricing games and discuss the consequences and the impact on net neutrality. Results show both positive and negative impacts of usage-based pricing on net neutrality. From the user perspective, the usage-based pricing does not show advantage over simple flat-rate pricing. On the positive side, our results also suggest that under certain circumstances cooperation between broadband providers can make the network be more profitable and yet sustainable. Based on the results, we discuss the practical feasibility of applying usage-based pricing for net neutrality under the presence of user loyalty.

1. Introduction

In essence, network neutrality is an approach to providing network access without unfair discrimination among applications, content or traffic sources. The net neutrality principle is sometime referred as the „all-bits-are-created-equal” principle. However, the question of how to define what is “fair”/“unfair” discrimination is still a controversial question, and the underlying economic and policy issues have not been fully discussed. In addition, the Internet now involves multiple stakeholders and there are conflicting interests between different (groups of) stakeholders, e.g. between the Internet Service Providers (ISPs) and the content providers, or between different network tiers in the network hierarchy. It is even

more important how these conflicting interests can be resolved. Internet Service Providers may have interest in traffic discrimination either for technological or economic purposes. Open questions that need to be addressed regarding this respect are broadband traffic management, traffic congestion, fair share of profits among the stakeholders, and last but not least, legislative measures to enforce it under European context. Traffic congestion, especially due to high-volume peer-to-peer traffic, has been a central argument for ISPs against the enforcement of net neutrality principles. However, many ISPs have blocked or throttled such traffic even during periods without congestion.

There are works to investigate the Internet access pricing [1,2,3,4] and also a broad literature in the area of modelling interactions between ISPs by game-theoretical tools. While these papers introduce and analyse complex models for the interactions of ISPs at different levels of hierarchy, they mostly assume a very simple user behaviour model when investigating those interactions: end-users choose the cheapest provider assuming that the quality of the certain services is the same. This assumption could be plausible in certain scenarios, but it could be misleading if there are loyal customer segments present in the market. On the other hand, economists are well aware of the notion of the consumer loyalty or brand loyalty, which exists in realistic markets. Practically speaking, a customer is loyal to a brand - under certain circumstances - when he/she purchases a product of that brand, even if there are cheaper substitutions on the market. Brand loyalty is rooted both in satisfaction towards a given brand and customers being reluctant to try substitute products. There is existing work [14] dealing with classification of buyers into loyalty groups, and a study [15] develops and empirically tests a model of antecedents of consumer loyalty towards ISPs. In [16], the authors use a game-theoretic framework to prove that if loyalty is an additional product of market share and penetration, customer retention strategies are more efficient for market leaders. Another study [10] analyses a duopolistic price setting game in which firms have loyal customer segments, but cannot distinguish them from price sensitive customers. They demonstrate that customer loyalty plays an important role in establishing the existence and identity of a price leader. The earlier works mentioned above provide valuable insights into the impact of brand loyalty on certain markets, but also inspire further investigations. First of all, how does customer loyalty affect a dynamic market of Internet access with usage-based pricing? Secondly, are there incentives for cooperative pricing from ISPs' side in a market where user loyalty is present? And last but not least, , what would be the impact of usage-based pricing on net neutrality under the presence of user loyalty from the game-theoretical perspective? We would like to note that user loyalty is only taken into account in [5, 6] using tools from game theory. However, these works only deal with loyalty issue of flat rate pricing, the research question of the impact of user loyalty on usage-based pricing and the consequences related to net neutrality have not been investigated.

In this paper, we provide a game-theoretic model for the interaction among the stakeholders in the provision of Internet access services. We first discuss the loyalty models for usage-based pricing for Internet access. Based on the models, we investigate the impact of customer loyalty on the usage-based price competition between local ISPs who sell

Internet access to end-users, both qualitatively and quantitatively. Using the tools from game theory, we compute the Nash equilibrium prices of the pricing games and discuss the consequences and the impact on net neutrality. To begin with, we consider the simplest case of a market with two ISPs competing under usage-based pricing with user loyalty and in a single shot setting. With respect to modelling usage-based pricing, we assume the simplest case when the prices paid by the customers are proportional to their real usage of traffic (linear relationship). We investigate the game where the players are competing ISPs and their strategies are setting the right price for access. This game is in fact an extension of the classical *Bertrand game* in classical economic science. We show that this game can have a unique Nash equilibrium in mixed strategies and in certain cases, we quantitatively compute the equilibrium profits of each ISPs.

We then extend the single shot game model to repeated game model where players are allowed to play with each other in multiple rounds. In these games, we investigate the Nash equilibrium states both in stage game and sub-game perfect equilibrium of the whole game. We construct the repeated extension of the single shot game with discount factor $\theta < 1$ and use the one-step deviation principle to prove sub-game perfection of given strategy set. Armed with the results from this analysis, we continue to investigate possible cooperative strategies for both ISPs to see to what extent and under what circumstances, cooperation can be profitable *and* stable from the game-theoretic point of view. Finally, we extend the game-theoretic models above with different user loyalty models to substantiate our previous findings.

2. Flat-rate versus usage-based pricing schemes

As Internet traffic increases, Internet pricing is a key issue to keep the whole system economically feasible and sustainable. Today, many countries are using flat-rate (a.k.a. all-you-can-eat) pricing schemes for broadband access networks. Under flat-rate pricing, the network operators charge every user the same price, regardless of the packet usage. Flat-rate pricing is widely applied because of its simplicity. In addition, it gives the end-users a sense of freedom, less concern and uncertainty about their actions regarding the volume of traffic they consume. However, flat-rate pricing fails to provide a price signal to the end-users, resulting in a congested network. Furthermore, flat rate is unfair to the network providers who carry the traffic because there is no added payment for more traffic transmitted. In consequence, this leads to an unfair business model among the stakeholders. To overcome this problem, various pricing schemes are suggested, in particular the usage-based pricing scheme (a.k.a. pay-as-you-go, tiered and metered pricing). We note that in order to properly understand usage based pricing, it is important to distinguish the difference in prices and price discrimination. Difference in prices is referred to the same types of traffic/services while price discrimination is about charging different price for different type of traffic/services. Under usage-based pricing scheme, Internet access providers charge users based on their packet usage. A key advantage of usage-based scheme is that it is a sensible way to price the demand of bandwidth-intensive users and applications and, in the process, alleviate network congestion, encourage new investment, and ensure

that average costs for consumers are more reasonable over time. Despite the possible benefits, there are many hurdles in implementing usage based pricing in practice. Usage based pricing is often opposed by many customers. As an example, there was a big uproar on this issue in Canada recently. Some even argue that usage-based billing only serves the interests of Internet Service Providers. As a consequence, the question is if it is possible to escape from flat rate pricing in practice and what would be the impact on net neutrality rules is still uncertain.

We witness, even before the net neutrality issue surface the discussions about the Internet, repeating patterns in the history of communication technologies, including ordinary mail, the telegraph, the telephone, and the list goes on. Interestingly enough, the typical story for each service is that quality rises, prices decrease, and usage increases to produce increased total revenues. At the same time, pricing becomes *simpler*. It has been seen many times in the past that the schemes that aimed to provide differentiated service levels and sophisticated pricing schemes are unlikely to be widely adopted. At present, it appears that as communication services become less expensive and are used more frequently, those arguments for differentiation (pricing included) loose out to *customers' desire* for simplicity. A success story of the late 1990s was the i-Mode service of the NTT DoCoMo in Japan, which was the first to offer high-speed mobile Internet access for a flat rate. It succeeded at a time when other mobile data services were failing, thanks partly to its decision on staying with flat rate pricing. The service is still very popular among users with more than 20 percent of NTT DoCoMo customers in Japan have signed up for flat rate mobile Internet plans. An interesting, but not yet fully answered question is, if this will still be the case under the fierce debates and consequences of fair profit sharing issue inherently associated with the network neutrality issue. It should be noted that price and quality differentiation are valuable tools that can provide higher revenues and increase social welfare. It is also shown that flat-rate pricing wastes resources, requires light users to subsidize heavy users, and consequently, may hinder deployment of broadband access. But again, due to network management issue, non-flat rate billing is also resource consuming from a broadband provider's viewpoint.

3. The impact of customer loyalty on pricing – a simple example

Suppose that there are two firms selling the same product in a given market. Assume further that they each consider three possible prices for their products depending on different market conditions and/or their competitor's prices: a high price (H), a medium price (M), and a low price (L). For the sake of simplicity, let the profits per product are 12 euros, 10 euros, and 6 euros, respectively, regardless of the volume of sales and a inelastic demand function, $D(p) = 10000$, i.e., customers will buy a total of 10000 without regard to its price (the market need).

Table1 Payoff matrix for the basic game

	H	M	L
H	(60,60)	(0,100)	(0,60)
M	(100,0)	(50,50)	(0,60)
L	(60,0)	(60,0)	(30,30)

Table2 Payoff matrix for the brand loyalty game

	H	M	L
H	(60,60)	(36,70)	(36,42)
M	(70,36)	(50,50)	(30,42)
L	(42,36)	(42,30)	(30,30)

This situation is similar to the Bertrand game if the prices set by the two firms are different, all the demand goes to the firm with a lower price, and if the prices are equal, the firm split the market evenly. It is easy to see that (L,L) is the unique Nash equilibrium of the game (see Table 1). Now, we change the conditions of the game a bit by introducing customer loyalty into the model. In this new model, the firm with higher price loses some but not all of its customers to the firm with a lower price. Assume that each firm has a loyal customer base that buys 3000 products, and the firms are actually competing for the remaining demand of 4000 products. In this new situation, the unique Nash equilibrium of the game shifts to (M,M) (see Table 2). The lesson we learn from this simple example is that customer loyalty removes the incentive to try to undercut the price of the other firm in order to steal market share. The games discussed so far demonstrate *quantitatively* how the existence of customer loyalty can affect the outcome of the price competition leading to the change of the equilibrium point. However, the broad existing literature assessing the pricing competition among Internet access providers (local ISPs) does not take user loyalty into consideration resulting in an overly simplified user model. This may lead to imprecise statements regarding equilibrium properties. Some natural questions emerge then: What is the particular quantitative impact of user loyalty on ISP usage-based pricing competition? What are the consequences of these impacts on net neutrality?

Reservation prices of customers Consumer population is heterogeneous in the sense that certain groups are willing to pay different amounts of money for the same service. In the

ideal world for the ISPs where they were able to perfectly identify the reservation price of each customer in the market, they could offer individually differentiated prices, thus squeezing off every cent from the users. Such a perfect identification of reservation prices is not likely in the real world. However, the reservation price of existing customer is generally higher than that of the newcomers, because existing customers tend to exhibit higher switching costs and also higher brand preference for that product. Furthermore, most of the analytical literature on price discrimination has found that it is optimal to penalize loyal users with higher price than switchers. While we do not introduce targeted pricing to our models, we assume that loyal users inherently tolerate a higher price than “switchers”, who are only interested in discount prices.

4. The basic game-theoretic model

We consider case when the total prices paid by the customers (the end users) consist of two parts: the first part is the monthly price (i.e. the flat rate), the other part is the price paid for the content consumed. In this paper, we focus on the impact of usage-based pricing mechanism, so we assume that the broadband providers have identical flat rates.

$$p_1^{total} = p_{flat} + p_1$$

$$p_2^{total} = p_{flat} + p_2$$

In the basic model, we assume two broadband providers play a game to settle on their usage-based prices. It is assumed in this paper that the usage-based pricing mechanism follow a linear characteristics. This is in line with many of usage-based pricing for information goods in practice. However, non-linear usage-based pricing as well as the combination of fix-rate and usage-based pricing mechanisms are used in practice as well, but we do not consider them in this basic model. Furthermore, it should be noted that usage-based pricing may involve transactional cost but in this paper, we assume this cost is negligible. The users are modelled through their demand response. The relationship is straightforward: the higher the price for content, the less the demand from the users. The users are assumed willing to pay a usage-based fee for service that requires both providers. We assume further that the demand-response of users, which corresponds to the amount of bandwidth they are ready to consume given prices p_1 and p_2 , follow a simple linear model. The justification of the assumption of linearity is that the usage-based pricing itself follows a linear pattern.

$$D = D_0 - d(p_1 + p_2)$$

With p_1 and p_2 are prices for content (in addition to monthly fees) set by ISP₁ and ISP₂, respectively, and d denotes the response coefficient to price variations. Parameter D_0 corresponds to demand for zero usage-based prices, which can be considered the demand under flat-rate pricing (i.e., $p_1=p_2=0$). The utility of ISP_{*i*} is $U_i = Dp_i$.

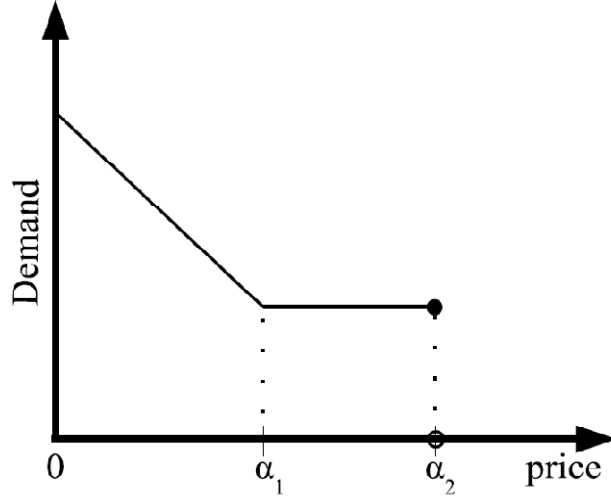


Figure 1 Price-demand linear relationship

Figure 1. shows the price-demand linear relationship with reservation prices α_1 and α_2 . Note that in this model, for the sake of simplicity, the utility function is assumed to have a linear relationship with the demand and price. In practice, the utility function may be characterized as an increasing, but concave function in the general form of $U_i = f(D, p_i)$.

Suppose that the broadband providers do not cooperate. This situation is similar to the classic game Cournot game in economic science. We can directly apply the results from the classical Cournot game to our case, but simple calculation by finding the saddle points here is also quite straightforward. A Nash equilibrium point (NEP) (p_1^*, p_2^*) of this two-player game satisfies:

$$\frac{\partial U_i}{\partial p_i}(p_1^*, p_2^*) = D^* - p_i^* d = 0 \text{ for } i=1, 2,$$

which leads to $p_1^* = p_2^* = D_0/(3d)$. The demand at equilibrium is thus $D^* = D_0/3$ and the revenue of each provider is $U_i^* = D_0^2/(9d)$.

Now suppose that there is a coalition between the broadband providers. Their overall utility is then $U_{total} = U_1 + U_2 = Dp$. Again, we assume here linear relationship between price and demand. Similarly, this model can be treated as a Cournot game for coalitional cases. We can directly apply the classical game to our model, but simple calculation is also straightforward here. Suppose that (p_1^*, p_2^*) is the NEP of the game. It should satisfy the following condition:

$$\frac{\partial U_{total}}{\partial p_i}(p_1^*, p_2^*) = D^* - d(p_1^* + p_2^*) = 0 \text{ for } i = 1, 2,$$

which yields $p^* = p_1^* + p_2^* = D_0/(2d)$. Other consequences follow. First, we can see that the demand at equilibrium is then $D^* = D_0/2$, which is greater than in the non-cooperative setting. The overall utility $U_{total}^* = D_0^2/(4d)$ is also greater than the overall utility for the

non-cooperative case. If we assume that both players share this revenue equally, the utility for each player is $U_{total}^* = D_0^2/(8d)$, which is greater than in the competitive case. As a result, we can conclude that, both players benefit from this coalition. However, it is important to note that these equilibrium states do not provide better solutions than in flat rate case as investigated in [7]. Moreover, usage-based pricing is less practical than flat rate pricing from the user perspective because it double charge the users, once for a monthly rate, and once for the content. Next, let us consider usage-based pricing under user loyalty.

5. The model with user loyalty

Now let us consider a market with two broadband providers (ISPs) competing in usage-based prices for a fixed numbers of customers. Customers are split into three partitions upon their brand loyalty: the first group consist of l_1 customers who are all loyal to ISP₁ in the sense that if ISP₁'s price p_1 less than or equal to a reservation value α , they choose ISP₁ as their service provider. The second group consists of l_2 loyal customers of ISP₂, and the third group contain n switchers, who buy service from the cheapest provider, if its price is not greater than α . If the broadband providers announce the same price, then half of the switchers chooses ISP₁ and the other half choose ISP₂. The flow of the game is that ISPs announce their prices simultaneously, and then customers make their choices. Without the lack of generality, we can assume that ISP₁ has the larger loyal user base, $l_1 > l_2, p_1 \leq \alpha, p_2 \leq \alpha$. Given these assumptions, the utility of ISP₁ can be expressed as

$$U_1(p_1, p_2) = \begin{cases} (l_1 + n)Dp_1/(l_1 + l_2 + n), & \text{if } p_1 < p_2 \\ (l_1 + 0.5n)Dp_1/(l_1 + l_2 + n), & \text{if } p_1 = p_2 \\ l_1Dp_1/(l_1 + l_2 + n), & \text{otherwise} \end{cases}$$

This game has a unique Nash equilibrium in mixed strategies. In this case, equilibrium profits are $U_1^* = \frac{l_1 \alpha D}{(l_1 + l_2 + n)}$, and $U_2^* = \frac{l_2 \alpha D}{(l_1 + l_2 + n)}$. As it can be noticed, the equilibrium has shifted compared to the simple Bertrand game without consumer loyalty with both parties having a positive payoff in equilibrium state.

We extend the previous model and we can show that the infinitely repeated game with the previous game as a stage game has a sub-game perfect equilibrium, which can be enforced by a threat strategy, namely the Nash equilibrium strategy of the stage game. It is indeed the case because the game is continuous at infinity since the discounted payoff in any step is bounded by $\alpha(l_1 + l_2)$. According to the one-step deviation principle we have the sub-game perfection of the equilibrium of the game.

Now, if the two providers cooperate and set their prices equal to the reservation value α , they will share switchers equally, in addition to keeping their own loyal users. In this case, similar to the basic model, it can be shown that the utilities of the providers in equilibrium states are higher than in non-cooperative model. This means that cooperation is highly

beneficial for both parties. If somehow one ISP tries to grab the whole free market in a single step k , the other ISP can counteract from step $(k + 1)$ by charging the Nash equilibrium price from the stage game further on (tit-for-tat strategy), which results in a decreased payoff for the traitor. This Nash reversion assures sub-game perfection of the repeated game. To summarize, under certain conditions for the discounted factor, the strategy profile *“cooperate until the other player deviates and then play accordingly to the Nash equilibrium in the stage game” in the usage-based pricing game is a sub-game perfect equilibrium for the repeated game.* As a consequence, under usage-based pricing regime, both the ISPs have an incentive to cooperate in order to maximize their profit on the long run. While explicit cooperation may be cumbersome in practice, this incentive may lead to discussions between service providers.

We can conclude that it is not easy to find an acceptable solution for all stakeholders under net neutrality, either with usage-based pricing or with flat-rate pricing. As it stands, usage-based pricing is preferred by network carrier why flat-rate pricing is friendlier and more acceptable toward the end-users. It is thus highly desirable to find a pricing model that lies somewhere between flat-rate and linear usage-based pricing model to accommodate all the stakeholders' interest.

6. Summary

In this paper, we have investigated net neutrality under usage-based pricing with user loyalty from a game-theoretic point of view. Our results show that usage-based pricing might be a fair solution from network providers' perspective that carries the traffic, but a number of issues emerge regarding the users' perspective. Usage-based pricing is itself a violation of net neutrality principle where broadband service providers charge the users more than once. We show that from the game-theoretic perspective, even in the presence of customer loyalty/loyal customers, usage-based pricing shows no clear advantages over flat-rate pricing. It is thus strongly advisable that any introduction of usage-based pricing in practice should take our findings into account. Many questions remain to be answered. First, it is difficult but highly desirable to find the optimal usage-based pricing schedule both for linear and non-linear cases. Second, in the situations where both fix-rate and usage-based pricing mechanisms are applied, for example, broadband providers may profit from low fixed-fee penetration pricing, but as the market matures, the optimal pricing mix should expand to include a wider range of usage-based pricing option. In other words, optimal combination of them would be needed. Furthermore, the extent of minimum fees, quantity discounts, and adoption levels across the different pricing schemes in different user loyalty models should be properly characterized. Modelling the adoption rate of users under these circumstances is yet another venue to be fully explored. Finally, under net neutrality regulation, we conclude that more investigation is needed to find an efficient pricing model that is acceptable for all the stakeholders in the network ecosystem. This question is part of our future investigation.

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