Network Neutrality and Provider Investment Incentives

John Musacchio
Technology and Information Management
University of California, Santa Cruz
Santa Cruz, CA
Email: johnm@soe.ucsc.edu

Jean Walrand and Galina Schwartz
Department of EECS
University of California, Berkeley
Berkeley, CA
Email: {wlr,gschwartz}@eecs.berkeley.edu

***Abstract*— This paper develops and analyzes a game theoretic model to study how the network regime (neutral or non-neutral) affects provider investment incentives, network quality and user prices. We formulate the conditions under which a non-neutral network is more favorable for providers and users. Our results indicate that the non-neutral regime is more favorable when the advertising rate is either low or high. When the advertising rate is high relative to the end-users' sensitivity to price, it is beneficial that the transit provider be able to charge the content providers who are not attached directly to them. This has the affect of passing some of the advertising revenue to the transit providers which in turn incentivizes them to invest. Conversely when the advertising rate is low, it is beneficial for all parties for transit providers to pay the content providers, which has the affect of sharing end-user revenue with the content providers in order to incentivize their investment. When the advertising rate is in the intermediate range, the neutral regime can be preferable (in terms of social welfare) because it prevents the multiple-indemnization that occurs in the non-neutral regime because transport providers tend to over-charge. In that latter case, the degree by which the neutral regime is preferable increases with the number of transit providers.**

I. Introduction

In 2006 there was a considerable divergence of opinions on the subject of net neutrality. Indeed the issue was intensely debated by law and policy makers, and the threat of the imposition of restrictive network regulations on internet service providers (ISPs) in order to achieve network neutrality seemed highly likely. Recently, the situation has begun to change. In June 2007, the Federal Trade Commission (FTC) issued a report, forcefully stating the lack of FTC support for network neutrality regulatory restraints, and warning of "potentially adverse and unintended effects of regulation" [1]. Similarly, on September 6, 2007 the Department of Justice issued comments "cautioning against premature regulation of the Internet," [2]. Thus, by the fall of 2007, the imminent threat of new regulation has diminished, and a consensus favoring the current (or unregulated) network regime seems to have emerged. Still, the debate about network neutrality is far from over.

The main aspects of network neutrality are user discrimination and service differentiation. A network is weakly neutral if it prohibits user discrimination (pricing users differently for the same service (see [3]) where in this context "user" means any party that uses a transit provider's network, which can either be a content provider or an "end" user.

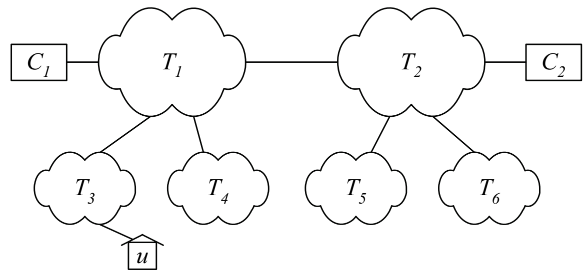

Fig. 1. Transport providers $\{T_1, \ldots, T_6\}$, content providers $\{C_1, C_2\}$ and end user u.

It is strongly neutral if it prohibits service differentiation (handling packets differently, see [4]). In this paper, we focus on user discrimination. For simplicity, henceforth we use the term neutral to mean weakly neutral and non-neutral to mean that user discrimination is allowed. To introduce the notation and illustrate the arguments for and against network neutrality, consider the network shown in Figure 1.

The figure shows end user u, transport providers $\{T_1, \ldots, T_6\}$, and content providers $\{C_1, C_2\}$. In this network, T_1 and T_2 are transit providers (i.e., transport providers who provide a direct access to a backbone, $T_3 - T_6$ are local internet service providers (ISPs). In the figure, the content providers are attached to a transit provider whereas a typical end user u is attached to an ISP. In a neutral network, end users and content providers pay only for their direct access. The transit providers charge the ISPs for carrying their traffic. The transit providers typically enter in peering agreements under which they agree to carry each other's traffic, usually free of charge. The transit providers charge the content providers for their attachment. Thus, in a neutral network, transport providers are prohibited from charging users not buying access directly from them.

In a non-neutral network, the transit provider T_2 is able to charge C_1 even though that content provider is not attached directly to T_2. Accordingly, T_2 could charge C_1 and not end user u for carrying their traffic, thus allowing transit providers to discriminate between users by charging them differently for the same service. In a non-neutral network, it is also possible for an ISP T_3 to charge C_1 for carrying its traffic.

The arguments pro and against weak neutrality can be summarized as follows. See [5], [6], [7], [8], [10], [11], and

[12] for more elaboration on those points.

Against Neutrality: This line of reasoning is usually expressed by transport (and transit) providers. Say that C_1 is a source of video streams that require a large bandwidth. Transport provider T_2 may argue that to accommodate the traffic needs of C_1, he must make substantial investments, which he cannot recover from the parties who buy access directly from him. For instance, if T_3 faces Bertrand competition from T_4, their access fees are set at marginal costs, which are much smaller than average costs due to the presence of substantial fixed costs. The content providers make additional advertising revenues when end users consume new high-bandwidth services, which justify their investments. If the transport providers cannot get a share of these additional revenues, they will not invest to increase the network capacity. The situation causes poor network quality, which reduces end user demand, which in turn leads to further reduction of incentives to invest for both provider types, transport and content. Said another way, the extra traffic of content providers imposes a negative externality on transit providers. This reduces network quality, which depresses end user demand, and through that investment incentives of all providers. The reduced network investments eventually make all parties worse off.

For Neutrality: This line of reasoning is usually expressed by content providers. If every transport provider can charge the content provider C_i, and not just the transport provider with which C_i is directly connected, the market power of the transport providers would increase dramatically. This would enable the transport providers to charge content providers more, and in turn, this would reduce the investment incentives for content providers thus lowering content quality. Another argument made by some neutrality advocates is that a small startup may be unable to afford the increased network fees before its popularity justifies sufficient advertising revenues, i.e., new content providers will face a higher barrier to entry, which facilitates more concentrated market structure for content providers.

To sum up, both lines of reasoning (of content and transport providers) argue that their preferred regime makes everyone better of, i.e., creates a Pareto improvement. Clearly both sides cannot be right; a more detailed analysis is required to clarify the trade-off. This paper explores how provider investments and revenues differ with network regime. We assume that the number of transport and content providers is fixed. That is, we do not consider the longer term impact of neutrality regulations on the structure of the industry.

In section II, we propose an economic model that relates the investments and prices to revenue for content and transport providers. We analyze the non-neutral regime in section III and the neutral regime in section IV. Section V is devoted to a comparison of the two regimes. In section VI we summarize our findings. The details of the analysis can be found in the appendix.

A. Related Work

There is a large literature on two-sided markets, and our model can be viewed in the two-sided market framework. For a survey of two-sided markets see for example [13] and [14]. The two-sided market literature studies markets in which a platform provider needs to attract two types of participants, and the presence of more of the one type makes the platform more valuable to the other type. [13] define the market as two-sided, when the volume of realized transactions depends not on the aggregate price level, but on the specifics of prices that the parties are charged. Using the two-sided market parlance, the transit providers of our model provide the platform, while end users are one type of participant and content providers are the other type. As will become clear when we describe the details of our model, the end users “single-home” or connect to one transit provider. In a non-neutral network, the content providers are forced to “multi-home” or pay multiple transit providers for delivering their content (see for example [14] section on the “competitive bottlenecks”). In contrast, the content providers in a neutral network, “single-home” or pay just one transit provider for connectivity. However a content provider that pays one transit provider in a neutral network enjoys the benefits of having connectivity to all the transit providers, because all the transit providers are interconnected. This is in contrast to most two-sided market models where the participants of one platform do not benefit from the presence of participants of another platform, i.e. Microsoft Xbox users do not benefit from more game makers writing Nintendo Playstation games. This is an important structural difference.

Other researchers have also used the ideas of two-sided markets to study network neutrality. Hermalin and Katz [15] model network neutrality as a restriction on product space, and consider whether ISPs should be allowed to offer more than one grade of service. Hogendorn [16] studies two-sided market where intermediaries sit between “conduits” and content providers. In his context, net-neutrality means content has open access to conduits where an “open access” regime affords open access to the intermediaries. Weiser [17] discusses policy issues related to two-sided markets.

The novelty of our model over other work in the two-sided market literature is our explicit modeling of platform investment choices. In the existing literature, the platform incurs the cost of serving the users, which usually is assumed linear in the number of users, but does not make an investment choice.

II. Model

For ease of exposition, we first describe a model with a single content provider and a single transport provider. We then explain the general model.

A. Simplified Model

Figure 2 shows advertisers (A), one content provider (C), one transport provider (T) and a set of users (U). The content provider invests c and the transport provider invests t. The content provider charges the advertisers a per click on a

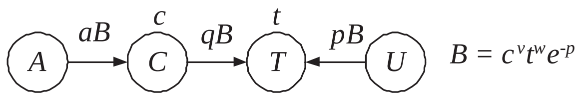

Fig. 2. The flows of dollars and bits in the simplified model.

sponsored ad. The transport provider charges the content provider q and the residential customer p, also per click on a sponsored ad. These normalized charges admit the following interpretation. The residential user pays a fixed monthly rate to his service provider to connect to the Internet and clicks a given average number of times on a sponsored ad each month. These values correspond to an average price p per click. The content provider pays the transport provider a monthly fee that depends on the traffic. For simplicity, we assume that the payment is proportional to the traffic rate and therefore corresponds to an average price q per click. We also assume that the charge a per click on a sponsored ad is fixed, thus ignoring the effect of the position or nature of the ad on the price.

The investments (c, t) and the price p result in a rate of clicks $B = c^v t^w e^{-p}$ where $v, w > 0$ and $v + w < 1$. This expression reflects the increasing attractiveness of the network to users as investments increase. Note that the investments have a diminishing return. The rate of clicks decreases with p, which models the decrease in the number of users who sign up with the provider if the monthly fee is higher. In this expression, the units of money are normalized so that the decay of the demand with p is e^{-p}; it corresponds to an exponential distribution of the willingness to pay the service provider.

The same units of money used to describe user price p should be used to measure advertising charge a. Thus, by normalizing the units of money so that the decay with respect to user price is e^{-p}, we are implicitly setting the units used to measure advertising rate a. For instance, suppose we wanted to change parameter settings to consider a situation where the rate of clicks with respect to user price decays twice as fast. In the original units of money the decay is like e^{-2p}, so by making the units of money half the size as the original units, we make our decay e^{-p} as required by the model. However, the change of units causes the numerical value of a increases. Thus as users become more sensitive to price, the value of a increases in comparison.

The net revenue of the content provider is

$$R_C = (a - q)B - \beta c = (a - q)c^v t^w e^{-p} - \beta c$$

where the term βc, with $\beta > 0$, is the opportunity cost of not investing c in some other option. Similarly, the net revenue of the transport provider is

$$R_T = (p + q)B - \beta t = (p + q)c^v t^w e^{-p} - \alpha t$$

where $\alpha > 0$.

Non-Neutral: In the non-neutral regime, the transport provider first chooses (t, p, q). The content provider then chooses c. The goal of the transport provider is to maximize R_T and that of the content provider is to maximize R_C. The justification for the order of actions is the difference in investment time scales. In our model, the transport provider decides the level of investment and the prices of the services before the content providers invest. This order is important for our results. For instance, if one assumes that the content provider chooses c first, then the transport provider can increase its revenue by increasing q and drive the revenue R_C negative. With this order of actions, the content provider's best first move is to select $c = 0$. Thus, this model results in a unique equilibrium under which $c = t = 0$. In actuality, if the transport providers increase q, the content providers would increase a, which should reduce the demand for advertising. This effect is not captured in our model.

For given values of (t, p, q), the optimal value of c is such that the derivative of R_C with respect to c is equal to zero. We find

$$c = \left[\frac{v(a-q)}{\beta} t^w e^{-p}\right]^{1/(1-v)}.$$

Substituting this expression in R_T, we find that

$$\begin{aligned} R_T &= (p+q)\left[\frac{v(a-q)}{\beta} t^w e^{-p}\right]^{v/(1-v)} t^w e^{-p} - \alpha t \\ &= (p+q)e^{-p/(1-v)}\left[\frac{v(a-q)}{\beta}\right]^{v/(1-v)} t^{w/(1-v)} - \alpha t. \end{aligned}$$

One can then find the values of (p, q, t) that maximize R_T. Since the results are a particular case of the general model, we postpone their discussion.

Neutral: In the neutral case, the transport provider first chooses $q = 0, p$ and t. The content provider then chooses c. The justification for $q = 0$ in the neutral case is that the content provider can sign up with the cheapest transport provider. Because of competition, the price is reduced to cost. In the non-neutral case, the content provider has no choice but to pay each transport provider, so that the competition does not reduce the price q.

With $q = 0$ one finds that

$$R_C = aB - \alpha c = ac^v t^w e^{-p} - \beta c.$$

For fixed values of (p, t), the content provider chooses the value of c that maximizes R_C. That value is

$$c = [\frac{va}{\beta} t^w e^{-p}]^{1/(1-v)}$$

and it results in

$$R_T = (1-v)e^{-1}(\frac{va}{\beta})^{v/(1-v)} t^{w/(1-v)} - \alpha t.$$

One can then find the values of (p, t) that maximize R_T. Once again, we postpone the discussion of the results to the general case.

B. General Model

In the general model, there are M content providers and N transport providers, as shown in Figure 3. Each transport provider T_n is attached to "end" users U_n $(n = 1, 2, \ldots, N)$ and charges them p_n per click. Transit provider T_n has its end user base U_n, over which it has a monopoly. Thus, the end users are divided between transit providers, with each transit provider having $1/N$ of the entire market. This assumption reflects the market power of regional transit providers. Each transport provider T_n also charges each content provider C_m an amount equal to q_n per click. Content provider C_m invests c_m and transport provider T_n invests t_n.

The rate B_n of clicks of end users U_n depends on the price p_n but also on the quality of the network, which we measure by provider investments. The rate of clicks B_n, which characterizes end user demand, depends on price and investments as

$$B_n = \left\{ \frac{1}{N^{1-w}} (c_1^v + \cdots + c_M^v) \times \left[(1-\rho) t_n^w + \frac{\rho}{N} (t_1^w + \cdots + t_N^w) \right] \right\} e^{-p_n} \quad (1)$$

where $\rho \in (0,1)$ and $v, w \geq 0$ with $v + w < 1$. For a given network quality (the expression in the curly brackets) the rate of clicks exponentially decreases with price p_n.

The term $c_1^v + \cdots + c_M^v$ is the value of the content providers as seen by a typical end user. This expression is concave in the investments of the individual providers. The interpretation is that each content provider adds value to the network, i.e., end users value a network in which content is produced by numerous content providers higher than the network in which the content is provided by a single provider whose investment equal cumulative investment of all content providers, i.e., as in classical monopolistic competition model by Dixit and Stiglits [18], our end users exhibit a preference for variety of content. The term in square brackets reflects the value of the transport provider investments for end users. When $\rho = 0$, End user U_n values investments of all transit providers equally, when $\rho = 1$, only investment of his local provider matters for the user, and when $\rho \in (0,1)$ end user U_n values investment of his local transport provider n more than investments of other provider $k \neq n$, still, investments of other providers add to the value of the network for end user U_n. This effect captures a typical network externality (see [19] for a discussion of investment spill-over effects). The factor $1/N^{1-w}$ is a convenient normalization. It reflects the division of the end user pool among N providers and it is justified as follows. Suppose there were no spill-over and each transit provider were to invest t/N. The total rate of clicks should be independent of N. In our model, the total rate of click is proportional to $(1/N^{1-w})(N(t/N)^w)$, which is indeed independent of N.

The rate R_{mn} of clicks from end users U_n to C_m is given by

$$R_{mn} = \frac{c_m^v}{c_1^v + \cdots + c_M^v} B_n. \quad (2)$$

Thus, the total rate of clicks for content provider C_m is given by

$$D_m = \sum_n R_{mn}. \quad (3)$$

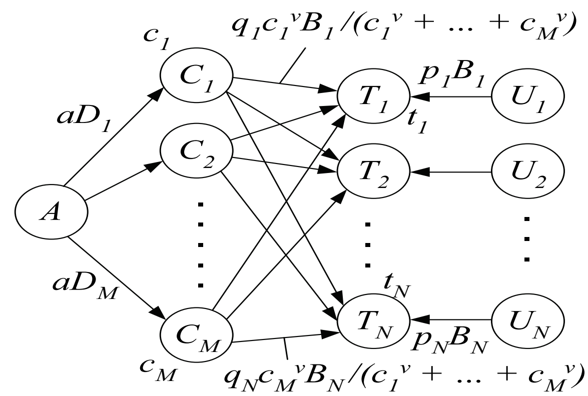

Fig. 3. The flows of dollars and bits.

We assume that content providers charge a fixed amount a per click to the advertisers. Each content provider's objective is to maximize its profit which is equal to net revenues from end user clicks net outside option. Thus

$$R_{Cm} = \sum_{n=1}^{N} (a - q_n) R_{mn} - \beta c_m \quad (4)$$

where the term $\beta > 0$ is the outside option (alternative use of funds c_m).

Transport provider T_n profit is

$$R_{Tn} = (p_n + q_n) B_n - \alpha t_n. \quad (5)$$

where $\alpha > 0$ is the outside option of the transit provider. We assume providers of each type are identical and we will focus on finding symmetric equilibria in both the neutral and non-neutral cases.

To compare the neutral and non-neutral cases, we make the following assumptions.

(a) Neutral Case: In stage 1 each T_n simultaneously chooses (t_n, p_n, q_n). In stage 2 each C_m chooses which transit provider to connect to and also chooses c_m.
(b) Non-Neutral Case: In stage 1 each T_n simultaneously chooses (t_n, p_n, q_n). In stage 2 each C_m chooses c_m.

In a neutral network, content providers need only pay the transit provider with which they are directly connected; transit providers elsewhere in the network cannot charge. Thus in a neutral network content providers can select which of the transit providers they will connect to and pay. This power to select a transit provider forces transit providers to compete on the price they charge content providers. The Bertrand competition between the transit providers in the neutral case forces the prices $\{q_n\}$ to be zero. In contrast, in an non-neutral network all transit providers have the ability to charge each content provider. This shifts the balance of prices in the direction of transit providers, and allows them to extract a non-zero price. In both regimes, we assume that content providers observe transport provider investments, and can adjust their investments based on the transport provider choices.

III. Non-Neutral Case

In a non-neutral regime, each transport providers chooses (t, p, q) and the each content provider chooses c. To analyze this situation, we study how C chooses the optimal c for a given (t, p, q). We then substitute that value of c in the expression for R_T and we optimize for (t, p, q).

The best choice for c_m given (t, p, q) maximizes

$$\begin{aligned} R_{Cm} &= aD_m - \sum_n q_n R_{mn} - \beta c_m \\ &= N^{w-1} c_m^v \left[\sum_n (a - q_n)((1-\rho)t_n^w + \right. \\ &\qquad \left. \frac{\rho}{N}(t_1^w + \cdots + t_N^w))e^{-p_n} \right] - \beta c_m. \end{aligned} \tag{6}$$

Note that this expression for R_{Cm} does not depend on investments of other content providers $C_j, j \neq m$. Therefore, each content provider need not consider the simultaneous investment decisions of the other content providers. Assuming that the term in square brackets is positive, we find that

$$\begin{aligned} \beta c_m^{1-v} &= vN^{w-1} \left[\sum_k (a - q_k) \times \right. \\ &\quad \left. ((1-\rho)t_k^w + \frac{\rho}{N}(t_1^w + \cdots + t_N^w))e^{-p_k} \right] \\ &=: \beta c^{1-v}. \end{aligned} \tag{7}$$

For that value of c_m, we find that

$$\begin{aligned} R_{Tn} &= MN^{w-1}(q_n + p_n)F_n e^{-p_n} (\frac{\nu}{N\beta})^{v/(1-v)} \times \\ &\quad [\sum_k (a - q_k)e^{-p_k} F_k]^{v/(1-v)} - \alpha t_n \end{aligned} \tag{8}$$

where

$$F_n = (1-\rho)t_k^w + \frac{\rho}{N}(t_1^w + \cdots + t_N^w) = \phi t_n^w + \frac{\rho}{N} \sum_{k \neq n} t_k^w \tag{9}$$

with

$$\phi := 1 - \rho + \frac{\rho}{N} < 1, \text{ if } N > 1. \tag{10}$$

The transport provider T_n chooses investment and prices (t_n, p_n, q_n) that maximize his profit given by equation (8). The simultaneous decisions of each of the transit providers affect each other, therefore in order to find a Nash equilibrium we need to identify a point where the best response functions intersect. Writing that the three corresponding partial derivatives of (8) are equal to zero, and then finding the symmetric intersection point of the best response functions, we find the following solutions (see [9]):

$$p_n = p = 1 - a; \tag{11}$$

$$q_n = q = a - \frac{v}{N(1-v) + v}; \tag{12}$$

$$t_n = t \text{ with } (Nt)^{1-v-w} = x^{1-v} y^v e^{-(1-a)}; \tag{13}$$

$$c_m = c \text{ with } c^{1-v-w} = x^w y^{1-w} e^{-(1-a)}; \tag{14}$$

$$R_C^{1-v-w} \triangleq \left(\frac{v(1-v)}{N(1-v) + v} \right)^{1-v-w} x^w y^v e^{-(1-a)}; \tag{15}$$

$$\begin{aligned} R_T^{1-v-w} &\triangleq \left(\frac{M(N(1-v) - wN\phi(1-v) - vw)}{N(N(1-v) + v)} \right)^{1-v-w} \\ &\qquad \times x^w y^v e^{-(1-a)} \end{aligned} \tag{16}$$

$$R_C/c = \frac{\beta(1-v)}{v} \tag{17}$$

$$R_T/t = \frac{\alpha}{w}[\frac{N(1-v)}{N\phi(1-v) + v} - w] \tag{18}$$

$$B^{1-v-w} = M^{1-v-w} x^w y^v e^{-(1-a)} \tag{19}$$

where R_C and R_T is the revenue of each content and transit provider respectively, $B := \sum_n B_n = \sum_m D_m$ is the total click rate and

$$x := \frac{Mw}{\alpha} \frac{N\phi(1-v) + v}{N(1-v) + v} \text{ and } y := \frac{1}{\beta} \frac{v^2}{N(1-v) + v}. \tag{20}$$

IV. Neutral Case

The neutral case is similar to the non-neutral case, except that $q_n = 0$ as we argued in section II for $n = 1, \ldots, N$. The best choice of c given $\{q_n = 0, p_n, t_n\}$ is such that

$$\beta c_m^{1-v} = vN^{-1}[\sum_k a((1-\rho)t_k^w + \frac{\rho}{N}(t_1^w + \cdots + t_N^w))e^{-p_k}] =: \beta c^{1-v}.$$

For that value of c_m, we find that

$$R_{Tn} = MN^{-1} p_n F_n e^{-p_n} (\frac{\nu}{\beta})^{v/(1-v)} [\sum_k a e^{-p_k} F_k]^{v/(1-v)} - \alpha t_n \tag{21}$$

where

$$F_n = \phi t_n^w + \frac{\rho}{N} \sum_{k \neq n} t_k^w.$$

The transport provider T_n chooses investment and price (t_n, p_n) that maximize the above expression. We find a symmetric Nash equilibrium by writing that the two corresponding partial derivatives of (21) with respect to a single transit providers actions are zero, and that the other transit providers make the same actions, and solving all of the resulting equations. This analysis leads to the following solutions (see [9]):

$$p_n = p_0 := \frac{N(1-v)}{N(1-v) + v}; \tag{22}$$

$$q_m = 0; \tag{23}$$

$$t_n = t_0 \text{ where } (Nt_0)^{1-v-w} = x^{1-v} y_0^v e^{-p_0} \tag{24}$$

$$c_m = c_0 \text{ where } c_0^{1-v-w} = x^w y_0^{1-w} e^{-p_0} \tag{25}$$

$$R_{C0}^{1-v-w} \triangleq (a(1-v))^{1-v-w} x^w y_0^v e^{-p_0} \tag{26}$$

$$R_{T0}^{1-v-w} \triangleq \left(\frac{M(N(1-v) - wN\phi(1-v) - wv)}{N(N(1-v)+v)}\right)^{1-v-w} \times x^w y_0^v e^{-p_0} \quad (27)$$

$$R_{C0}/c_0 = \frac{\beta(1-v)}{v} \quad (28)$$

$$R_{T0}/t_0 = \frac{\alpha}{w}[\frac{N(1-v)}{N\phi(1-v)+v} - w] \quad (29)$$

$$B_0^{1-v-w} = M^{1-v-w} x^w y_0^v e^{-p_0} \quad (30)$$

where R_{C0} and R_{T0} is the revenue of each content and transit provider respectively, B_0 is the total click rate, x is given in (20), and

$$y_0 := \frac{av}{\beta}. \quad (31)$$

V. COMPARISON

In this section we compare the Nash equilibria of the two regimes. In section V-A we derive expressions for the welfare of end users, and the ratio of social welfare in the neutral vs. non-neutral regimes. In section V-B we demonstrate that the return on investments is the same in both regimes. In section V-C we compare the revenue and social welfare of the two regimes for a range of parameters.

A. User Welfare and Social Welfare

Before proceeding we define the following notation.

$$\pi := \frac{v}{N(1-v)+v}. \quad (32)$$

In order to compute end user welfare, we use the total click rate as aggregate user demand. This enables us to calculate consumer surplus and use it as a measure of end user welfare. We compute the consumer surplus by taking the integral of the demand function from the equilibrium price to infinity. This integral is taken with the investment levels of content and transit providers fixed. We find

$$W_U(\text{non-neutral}) = Mx^{w/(1-v-w)} y^{v/(1-v-w)} e^{-\frac{1-a}{1-v-w}}.$$

The expression for the neutral case is the same, but with y exchanged for y_0. The ratio of the social welfare in the neutral vs. non neutral cases has the form

$$\frac{W_U(\text{neutral}) + NR_T(\text{neutral}) + MR_C(\text{neutral})}{W_U(\text{non-neutral}) + NR_T(\text{non-neutral}) + MR_C(\text{non-neutral})} = \frac{1 + a(1-v) + (\pi/v)(N(1-v) - wN\phi(1-v) - wv)}{1 + \pi(1-v)(\pi/v)(N(1-v) - wN\phi(1-v) - wv)} \times [(a/\pi)^v e^{\pi - a}]^{1/(1-w-v)}.$$

B. Return on Investment

Proposition 1:

$$p = 1 - a.$$

Also, we note that

$$p + q = p_0 = 1 - \pi.$$

Moreover,

$$\frac{R_C}{c} = \frac{R_{C0}}{c_0} \text{ and } \frac{R_T}{t} = \frac{R_{T0}}{t_0}.$$

That is, the total revenue per click of the transit providers is the same in both regimes and so are the rate of return on investments of the content and transit providers.
The rate of return on investments are the same in both the neutral and non-neutral cases. However, the size of those investments and resulting profits might be quite different in the two regimes as we see in the next subsection.

C. Comparative Statics

Dividing the expressions for the neutral case by the corresponding expressions the non-neutral case, we define ratios such as

$$r(R_C) := \left(\frac{R_C(\text{neutral})}{R_C(\text{non-neutral})}\right)^{1-v-w}$$

where $R_C(\text{non-neutral})$ is the revenue per content provider in the non-neutral case as expressed in (15) and $R_C(\text{neutral})$ is the revenue per content provider in the neutral case (26). We define $r(c), r(t)$, and $r(R_T)$ similarly. We find

$$r(R_T) = r(t) = r(B) = \left(\frac{a}{\pi}\right)^v e^{\pi - a} \quad (33)$$

$$r(R_C) = r(c) = \left(\frac{a}{\pi}\right)^{1-w} e^{\pi - a} \quad (34)$$

Figure 4 shows the ratios of revenues in the neutral vs. the non-neutral cases for both content and transit providers. Figure 5 shows the same ratios, but for different values of v and w. The figures show that for small or large values of a the non-neutral regime is preferable to both content and transit providers. (Here we say “preferable” in that the revenues are larger, though we have seen that the rate of return on investments are the same.) For mid range values of a, the neutral regime is preferable to both, though the values of a where the transition between neutral being preferable to non-neutral are not exactly the same for content providers and transit providers. Furthermore, as the number N of transit providers increases, the range of values of a for which neutral is superior increases, while also the degree by which it is superior (in terms of revenues to content and transit providers) increases.

These results can be explained by the following reasoning. When a is large, the content providers’ revenues from advertising are relatively high, and the transit providers’ revenue from end users are relatively low. Because of this, the transit providers do not have a strong incentive to invest, unless they can extract some of the content providers’ advertising revenue by charging the content providers. Thus in the neutral regime, the transit providers under invest, making the rewards for them as well as content providers less than it could have been in a non-neutral regime.

When a is very small, the revenues from content providers’ advertising revenue is relatively low, and the transit provider’s end user revenue is relatively high. In order to get the content providers to invest adequately, the transit providers need to pay the content providers. That is why for small enough a the price q is negative (see Figure 6),

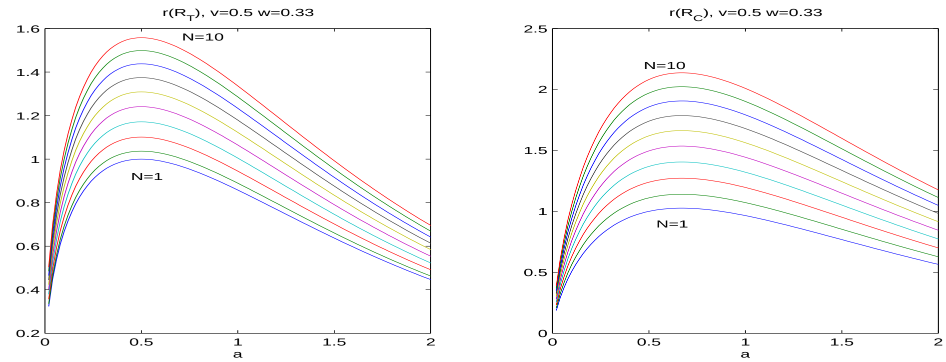

Fig. 4. The ratios of revenues $v = 0.5, w = 0.33$ for different values of N.

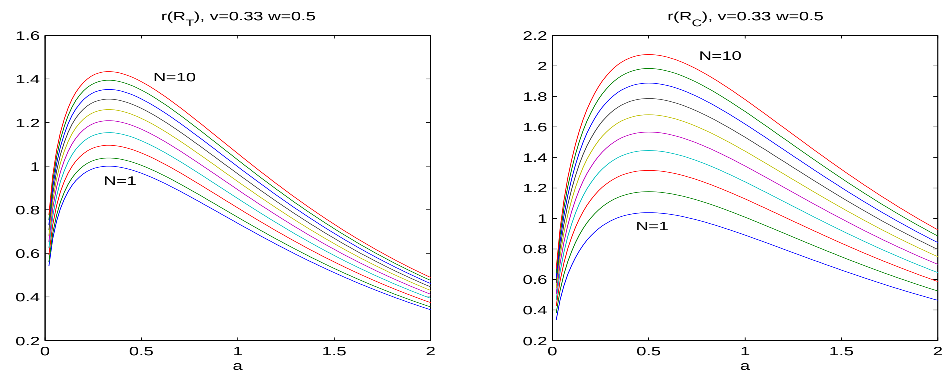

Fig. 5. The ratios of revenues $v = 0.33, w = 0.5$ for different values of N.

representing a per click payment from the transit providers to the content providers.

It is also interesting to note that our content providers obviously get some share of the surplus generated jointly by them and the transit providers in the-neutral case. This is in contrast to the multi-homing case of [14] (which is roughly analogous to our non-neutral case), the surplus is fully extracted from group-2 agents (content providers in our case) – the entire surplus is shared between between the platform and the end users. We do not have this extreme result, because in our model content providers invest after transit providers announce prices. Thus, transit provider commitment to prices permits content providers to retain a positive fraction of the surplus.

Finally, when a is in between the two extremes both content providers and transit providers have adequate incentive to invest. However another effect comes into play. As N increases in the non-neutral regime, more transit providers charge each content provider, thus reducing the incentive for content providers to invest and, consequently, reducing the demand for content and the revenues of the other transport providers. This is an example of multiple-indemnization, particularly simple in the "castles on the Rhine effect" where each castle owner increases transit tolls on passing traffic without realizing that if all castles do the same, the traffic on the Rhine will decrease [20].

Figure 7 shows a three dimensional plot of the ratio of social welfare in the neutral vs. non-neutral cases. The plot shows how the ratio changes for different N and a. The

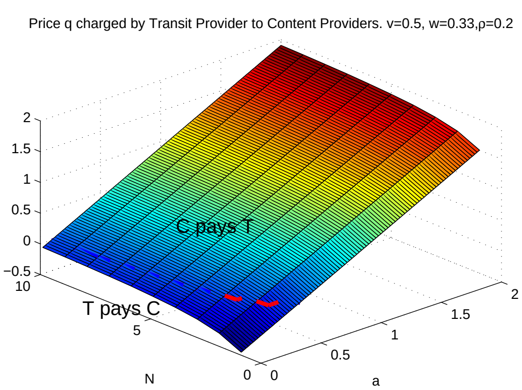

Fig. 6. The price q charged by transit providers to content providers. The price is negative for small enough a.

second panel of Figure 7 is essentially a simplified version of the first panel showing just the boundaries in the parameter space where neutral is preferable to neutral and vice versa.

VI. Conclusions

We study how the network regime affects investment incentives of transit and content providers. We show that parameters such as advertising rate and the number of transit providers influence whether a neutral or non-neutral regime achieves a higher social welfare. From our results, when the advertising rates is an extreme value, either large or small, the non-neutral regime is preferable. Otherwise, multiple indemnization becomes more important in a non-

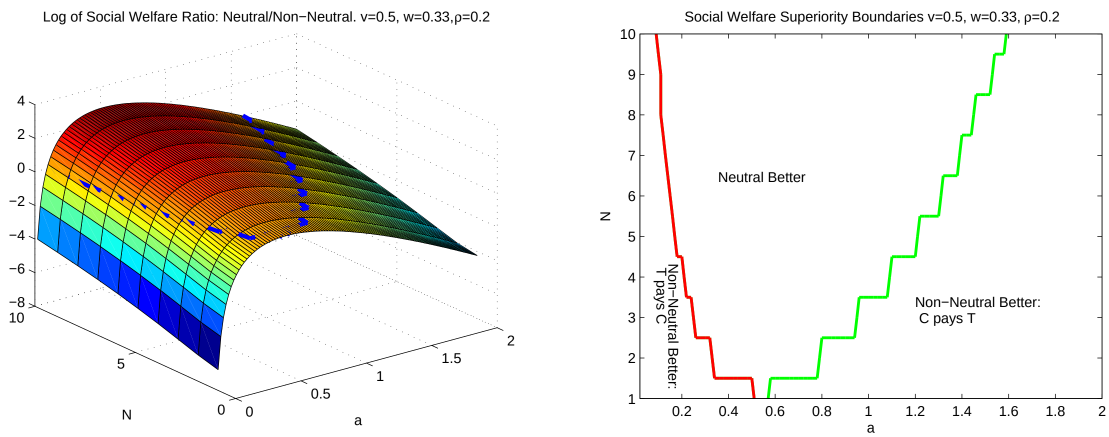

Fig. 7. Left: The Log of the Ratio of Social Welfare. Neutral Welfare divided by Non-Neutral Welfare. Right: Regions of Social Welfare Superiority for Neutral vs. Non-Neutral.

neutral network, making it less desirable than the neutral regime. That is, transit providers in a non-neutral regime have the potential to over charge content providers, and this effect becomes stronger as the number of transit providers increases.

In our comparison of the neutral and non-neutral networks we assume that the transport providers choose their strategy first and that the content providers follow. We justify this assumption by the difference in time scales of investments. There are several limitations of our model. First we have a fixed number of network providers that is independent of the network regime. Second, we do not consider heterogeneity in the providers nor in the end users. Third, we assume full commitment to the declared prices, i.e. the transit providers cannot later change the prices declare in the first stage. We also have not modeled the price content providers charge advertisers as a decision variable, but we have modeled the price transit providers charge end users. Though we feel that the present model has the right features to capture the effects of interest in this paper, in future models we might also consider the pricing between content providers and advertisers endogenously.

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