European Journal of Operational Research 207 (2010) 1658–1668

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Innovative Applications of O.R.

Pricing peer-produced services: Quality, capacity, and competition issues

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ARTICLE INFO

Article history:
Received 6 December 2008
Accepted 16 June 2010
Available online 22 June 2010

Keywords:
Game theory
Pricing
Web 2.0
Peer production
Service quality
Competition

ABSTRACT

Peer production has played an important role in the economics of Web 2.0 related services in which user participation and contribution become the main driving dynamics. However, the quality of peer-produced services is uncertain because of inherently decentralized and heterogeneous participants. In the paper, utilizing reliability and game theoretic models, we develop a QoS measure and pricing schemes for this emerging type of service under various market structures. Our results suggest that a monopolistic platform provider has no incentive to offer multiple quality classes of service. Two competing platform providers may offer identical service contracts but still receive non-negative profit. If they offer heterogeneous service contracts, the provider with the lower quality service may provide higher quality than he advertises. This research contributes to the literature with a number of unique and interesting implications for the issues of service contract design, capacity planning, and market interactions for operations of community-based or peer-produced services.

1. Introduction

In the wave of Web 2.0, the power of online community is addressed and peer production is emerging as a major economic force impacting various industries. Online communities are gaining momentum on the web and are reshaping the way how information is consumed and produced (Kolbitsch and Maurer, 2006). Companies and consumers had different roles of production and consumption in the traditional value creation process, but peer production creates a new dynamic to the producer/customer relationship. Many initiatives have been launched to deal with this changing world and some have been successful, but it is still pretty new to most companies. Different terms can be found to denote the growing new phenomenon such as peer production (Benkler, 2002; Benkler and Nissenbaum, 2006) and user generated content (Oded, 2007), hereinafter we refer these production types as *peer production*, and the platforms/systems which support peer-production processes are named as *peer-produced services*. There exist many popular realized peer production based services, for example, information services like Experts-Exchange and Yahoo! Answers. However, it is still an evolving concept, and there is no single dominate business model at present. We observed that some companies provided similar service, but after years only a few still there.

Booming Web 2.0 services are facing challenges to monetize the success (Höegg et al., 2006), and so are peer-produced services. The business models of Web 2.0 related services are becoming increasingly promising. Since peer production is one of the main distinguishing characteristics of Web 2.0 service, it is desirable to analyze and extend the knowledge of the peer production based service market. Due to the decentralized and loosely self-enforced contribution, the quality of peer-produced services is uncertain. In contrast with traditional firm-produced products, the quality of peer-produced services is associated with the contribution rate of heterogeneous participants, the number of participants, and the capacity-limited platform (Agichtein et al., 2008). Product or service differentiation is a common marketing technique exploited for profit improvement. As any pricing schemes should be realized based on the classes of service quality, it is important to develop an appropriate model to evaluate the quality of service (QoS) deliverable to the users before they can subscribe to the services.

In this paper, we propose a general framework for investigating the pricing and quality strategies of peer-produced content services based on the framework of service-level agreement (SLA) under various market structure settings, but do not limit it to specific business applications. To generalize our research, the services which share the following characteristics are defined as peer-produced services. First, there is a platform which enables users to contribute. Second, the contents within a platform are contributed (produced) and requested (consumed) by the platform users. Third, the users are autonomous and individual contribution is stochastic. Due to the decentralized and self-motivated nature, the quality of peer-production-related service is hard to evaluate. A simple yet feasible way is proposed to measure the quality of peer-produced services, and develop optimal service quality levels, pricing

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doi:10.1016/j.ejor.2010.06.023

schemes, and capacity choice for different market settings. This study has the following salient features that differentiate it from the past literature. First, we combine reliability and game theoretical approaches to model the pricing schemes of participant-generated services. Second, we propose a simple but feasible way to set up service-level agreements for participant-generated services. Third, we analyze the implications for service differentiation and competition in the market of participant-generated services. Fourth, we examine the role of platform capacity and the investment issue for participant-generated services.

The main unique findings of this study are as follows. First, we find that the service quality of peer-produced services increases with the heterogeneity of the participants. Second, a monopolistic platform provider will never offer multiple quality classes of peer-produced services and never over-provide a quality level higher than advertised. Third, in a duopolistic market, even when offering identical SLA contracts, each competing provider can still receive non-negative profit. Fourth, in a duopolistic market, the provider with the lower service quality level may offer a quality level higher that it advertises in the SLA contract.

The remainder of the paper is organized as follows. In Section 2, we review the related literature. The service quality evaluation and the user decision models are described in Section 3. In Section 4, we analyze the baseline model of price scheme and capacity choice for a monopolistic market and extend the analysis to a duopolistic market in Section 5. In Section 6, we numerically compare the SLA contracts, capacity, and profit levels under different market scenarios. Finally, case study and managerial implications are presented in Sections 7 and 8 provides concluding remarks and offers future research directions.

2. Literature review

Unlike traditional products, the quality of peer production is associated with the contribution rate of heterogeneous participants, the number of participants, and the capacity-limited community platform. As any pricing schemes should be realized based on the classes of service quality, it is important to develop an appropriate model to evaluate the quality of service (QoS) deliverable to the users before they can subscribe to the services. While extensive existing works on product differentiation and competition are mostly conducted for the traditional firm-produced products, little is targeted to the emerging peer-produced services.

2.1. Peer-produced service

Peer production was introduced to describe the new Web 2.0 model of economic production based on online community activities (Benkler, 2002), and peer participants depend on self-organized communities to produce a shared outcome (Tapscott and Williams, 2006). Although peer production is a new concept, it has been proven to be beneficial. The advantages of peer production are known from many pieces of research (Benkler, 2002; Schonfeld, 2005), and it has been proven to be efficient (Kogut and Metiu, 2001). According to Linus's Law (Raymond, 1999), the number of peer participants contributing to specific content provides a useful indication of its quality. Past studies also suggested the importance of peer participants' contribution to the service quality (Lerner and Tirole, 2002; Lakhani and Hippel, 2003; Höegg et al., 2006). However, the challenges in forming an online community are the willingness to contribute and the development of peer participants (Koh and Kim, 2004). The contribution behavior of online community participants was covered in other researches (Koh and Kim, 2004; Bagozzi and Dholakia, 2006; Baldwin and Clark, 2006), and theories like Social Cognitive Theory, Social Capital Theory and Organizational Citizenship Behaviors are applied to help clarify contribution behavior (Koh and Kim, 2004; Chiu et al., 2006). Peer production depends on peer participants' action that is self-organized and decentralized. However, due to the variety of peer participants and loosely altruistic contribution, the quality of peer-produced services is uncertain and difficult to measure.

The existing works generally do not cover the profitability issue of peer-produced services from the perspective of service platform provider. In our research, we develop peer-produced services business models (pricing schemes) based on the advertised quality level, which is mainly determined by collective contribution of participants. Rather than controlling the quality, we propose a participant-based metric to measure the service quality. Furthermore, a QoS-based pricing mechanism is proposed to achieve the purpose of service differentiation.

2.2. Quality, capacity and pricing

Quality can be defined as the ability of a service to meet or exceed customer expectations (Vörös, 2006). It is critical for peer production to be successful (Benkler, 2002; Benkler and Nissenbaum, 2006), and the issues on quality control/assurance/improvement have been studied (Stvilia et al., 2008; Hütter et al., 2008). Economic models dealing with price and quality relationships typically take quality into consideration (Karmarkar and Pitbladdo, 1993; Zhang et al., 2009), and it is usually treated as a decision variable (Teng and Thompson, 1996). From the viewpoint of potential users, the service quality and price could influence their willingness to adopt directly. However, in the real world the information on service quality is hard to measure and rarely revealed to users. QoS is a comparison between what a user feels should be offered and what is provided (Pitt et al., 1995), and beliefs about a service's perceived quality influence one's attitude toward using this service (Hwang and Kim, 2007). QoS uncertainty is common for services, and a useful mechanism is the offering of a QoS guarantee (Bhargava and Sun, 2008). A QoS guarantee is a business contract that describes the service-level agreement (SLA) that a provider needs to commit. A SLA is a statement of the expectations and obligations that exist between a service provider and a customer. Within an SLA, pricing should be aligned with service-level priority differentials, and with the service provider's achievement of service-level targets (Fitsilis, 2006).

Many services that exhibit QoS uncertainty are offered under flat-rate pricing, but quality uncertainty reduces the effectiveness of pricing strategy (Bhargava and Sun, 2008). Besides, QoS promises are usually ill-defined. An alternative to solve this difficulty is to monitor long-term QoS and provide a statistical guarantee (Bhargava and Sun, 2008). From the real world cases and past literatures, we find something interesting. First, past researches focused mainly on quality control. However, it has never been easy to control various participants over the network. Second, the price of existing services is flat-rate pricing and the quality is ignored. Third, the number of participants within the service platform is crucial to QoS, it would be an important issue for service provider. Nevertheless, it is often ignored.

When talking about QoS, a large number of users were considered to be a negative factor to service quality because of congestion problem. Past research showed that the quality of service degrades as user increases (Westland, 1992). Nevertheless, in peer-produced services the more the users the better the service quality. QoS of peer-production service is determined by the individual contribution rate and the number of participants. Because contribution rate varies, it is difficult to estimate the exact quality of service level. In the research, a metric is developed to estimate a lower bound of service quality, and SLA business contract can be further be implemented. As the service quality level is associated with the available number of participants, the price and capacity should be considered. Price level can adjust the number of participants but the number of participants are limited by the available capacity. Capacity is usually considered as a QoS constraint (Song and Jamalipour, 2008), and the number of participants is constrained by the capacity. To reflect the real cases and make our model reasonable and feasible, the capacity is assumed to be limited. In a short run, capacity is fixed and treated as an exogenous parameter (Falkner et al., 2000; Rho et al., 2007; Zhang et al., 2009). However, in a long run, considering the capacity size and investment cost, platform providers can plan appropriate capacity to improve the profit (Goyal and Netessine, 2007; Anupindi and Jiang, 2008).

3. The model

Our settings follow the techniques commonly used to model the market with price and quality competition (Banker et al., 1998; Zhang et al., 2008). Consider a peer-produced service market that includes the participatory platform (infrastructure) providers and peer participants. We focus on the profit-maximizing platform providers whose revenue is mainly generated from the subscription fee. Conceptually, peer-produced services are created based on the community activities. Peer participants benefit from exploiting the content, knowledge, or computing resource contributed by other participants in the networks. As the participants voluntarily contribute their content, the contribution levels are heterogeneous among different peer participants. As a result, the quality of the service becomes uncertain and is closely associated with the level of individual contribution and the number of peer participants. In the following, we first develop a model to represent the QoS level and potential peer participants decide whether to join the community after considering the advertised QoS, price, and their own individual valuation of the service. The notations used are listed in Table 1 and discussed in the corresponding subsections.

3.1. Quality of service

The contribution rate h_i denotes the resource (content, knowledge, information, service, etc.) availability of peer participant i, where $0 \leqslant h_i \leqslant 1$. Since the provision of the resource in a distributed system is stochastic, from the perspective of reliability theory, h_i can be interpreted as the probability that a given requested resource can be found from participant i. Notice that the contribution rate among individuals is independent; therefore, it is possible that more than one peer provider will provide the same resource in the same time. Assume the total potential number of users of the peer-production system is η_0 and the total number of subscribed users is η. The exact quality measurement of the peer-production system is estimated as $H = 1 - \prod_{i=1}^{\eta}(1 - h_i)$. However, it is difficult to measure h_i for individuals in a large community. This makes it hard for the service provider to set the SLA. To conquer this, we use $\bar{h}$ the mean of the individual resource availability of peer participants in the peer-production system, to evaluate the lower bound of the QoS. The rationales of this approach can be explained as follows. According to the arithmetic and geometric mean inequality (Alzer, 1996), we have

$$H = 1 - \prod_{i=1}^{\eta}(1 - h_i) \geqslant 1 - \left(1 - \left(\sum_{i=1}^{\eta} h_i\right) \Big/ \eta\right)^{\eta} = 1 - (1 - \bar{h})^{\eta} = \overline{H}. \quad (1)$$

Proposition 1. (i) *Given an equivalent mean of contribution rate, the service quality of a peer-production system with heterogeneous peer participants is always better than homogeneous ones.* (ii) *As a result, the lower bound of service quality can be measured as long as only the average contribution rate is known.*

Researches on an electronic-based brainstorming system like a group support system have shown that the diversity of participants may be of little benefit to group creativity (Bantel and Jackson, 1989). Service quality level of peer-produced service is uneasily to be measured because of uncertain individual contribution. As far as we know, peer-produced service providers do not reveal their QoS information. Consequently, it is difficult for users to judge whether to subscribe or not. From the viewpoint of service providers, Proposition 1 indicates that the lower bound of service quality is obtainable when the information of the average contribution rate is known. The benefits of this approach are twofold. First, the average contribution rate $\bar{h}$ is comparatively easy to measure even if the distribution of the individual contribution rate is unknown. Second, the lower bound of the service quality ensures the level of quality to be delivered to the subscribers.

3.2. Subscription functions

The peer participants are heterogeneous on the valuation of the service. We assume that consumers have an independent value v_i for a service that is unknown to providers and uniformly distributed in interval [0, V]. U_i is the utility function, and p is the price of the service. The utility function of user i can be formulated as

$$U_i = \begin{cases} v_i H - p & \text{if users subscribe,} \\ 0 & \text{if users do not subscribe.} \end{cases}$$

Table 1
Model parameters.

Parameters	Description
h_i	Individual contribution rate of peer participants i, $h_i \in [0,1]$
$\bar{h}$	Average contribution rate of peer participants, $\bar{h} \in [0,1]$
η_0	Total number of potential users, $\eta_0 \geqslant 0$
η	Subscribed users of peer-production system[a], $\eta \geqslant 0$
$\hat{\eta}$	Minimum number of subscribers to ensure the advertised quality, $\hat{\eta} \geqslant 0$
η_k	Service quality capacity of the platform, $\eta_k \geqslant 0$
H	Service quality of the peer-production system[a], $H \in [0,1]$
$\overline{H}$	Lower bound of service quality[a], $\overline{H} \in [0,1]$
v_i	Valuation of peer participant i, $v_i \in [0, V]$, where $V > 0$ is the upper bound
p	Price of the peer-production system related services[a]
U_i	Utility function of a typical peer participant i
$K(\eta_k)$	Platform investment in peer-production system with capacity η_k
π	The profit of service platform provider[a]

[a] m: monopoly; c: duopoly, homogeneous; h: duopoly, high quality; l: duopoly, low quality.

In equilibrium, only the customers with utility $U_i \geqslant 0$ will subscribe to the system. That is, the total demand comes from those participants with value $v_i \geqslant \hat{v} = p/H$ (Shy, 1995) and the number of subscriptions is derived as

$$\eta = \left(1 - \frac{p}{VH}\right)\eta_0. \tag{2}$$

4. Monopolistic market

The objective of the monopolistic service provider is to choose an SLA and price to maximize the profit. The detailed enforcement of the SLA agreement is beyond the scope of the paper. Here, we assume the penalty for violating the service quality guarantee is huge, such that the firm definitely commits to the advertised SLA. A platform provider may provide services with differentiated QoS levels. Q denotes the set of all differentiated QoS levels offered by the platform providers and q a typical SLA level. $K(\eta_{kq})$ is the cost of infrastructure that affords the accommodation of η_{kq} number of users at the same time for the service with QoS level q.

Following Zhang et al. (2009), the general formulation of the objective function of the service provider with SLA constraint can be written as

$$\begin{aligned} &\text{Max}_{H_q,p_q} \quad \pi_m = \sum_q (p_q\eta_q - K(\eta_{kq})) \\ &\text{s.t.} \qquad H_q \leqslant \overline{H}_q, \quad \eta_q \leqslant \eta_{kq}, \ \forall q \in Q. \end{aligned} \tag{3}$$

In the following, we first discuss a baseline model in which only a single SLA level is offered by the monopolistic provider and then discuss the feasibility of offering multiple SLA levels.

4.1. Single service class

If only a single service quality level is provided, the objective function becomes

$$\begin{aligned} &\text{Max}_{H,p} \quad \pi_m = p\eta - K(\eta_k) \\ &\text{s.t.} \qquad H \leqslant \overline{H}, \quad \eta \leqslant \eta_k. \end{aligned} \tag{4}$$

As there is only one SLA level, the subscript q in quality level H is omitted here.

4.1.1. Optimal pricing

As the provider cannot advertise a service quality level higher than the system can actually provide, we have the minimum number of subscribers to ensure the advertised quality service, $\hat{\eta} = \ln(1-H)/\ln(1-\bar{h})$. In addition, the upper bound of subscribed users is limited to the platform capacity η_k. In the following analysis, we assume that the capacity of the infrastructure is large enough to accommodate sufficient participants to maintain SLA and that the provider would not overinvest beyond the potential market, which means $\hat{\eta} \leqslant \eta_k \leqslant \eta_0$. Hence, the feasible subscription demand should satisfy the condition $\hat{\eta} \leqslant \eta \leqslant \eta_k \leqslant \eta_0$. Solving the first-order condition $\partial\pi_m/\partial p = 0$, we obtain the optimal price $p^* = VH/2$ and the subscription demand $\eta_0/2$. Thus, to ensure the satisfaction of the SLA, the total number of all the potential participants of the system should be large enough to satisfy the condition $\eta_0 \geqslant 2\hat{\eta}$. Obviously, if the potential market is too small ($\eta_0 < \hat{\eta}$), the QoS level will never be satisfied and consequently there will be no subscribers at all.

A low user population inherently leads to low service quality. Therefore, it becomes difficult to charge a subscription fee when the community is initiated and introduced at an early development stage. As the user population grows, more participants join and the quality is then improved, and users are willing to pay more as long as the SLA can be enforced. As the potential users grow to the interval $\hat{\eta} \leqslant \eta_0 < 2\hat{\eta}$, the optimal number of subscribed users is $\eta_m^* = \hat{\eta}$ and the SLA is promised. If the market keeps growing to the interval $2\hat{\eta} \leqslant \eta_0 \leqslant 2\eta_k$, the optimal subscription demand becomes $\eta_m^* = \eta_0/2$. In this scenario, the actual service quality level is higher than advertised. However, if the market is very large, such that $\eta_0 > 2\eta_k$, the number of subscribers is bounded by the platform capacity and we have $\eta_m^* = \eta_k$. The optimal number of subscriptions under different intervals is summarized in (5).

$$\eta_m^* = \begin{cases} \eta_k & \text{if } \eta_0 > 2\eta_k, \\ \eta_0/2 & \text{if } 2\hat{\eta} \leqslant \eta_0 \leqslant 2\eta_k, \\ \hat{\eta} & \text{if } \hat{\eta} \leqslant \eta_0 < 2\hat{\eta}, \\ 0 & \text{if } \eta_0 < \hat{\eta}. \end{cases} \tag{5}$$

From (2), we have the price levels under the corresponding intervals:

$$p_m^* = \begin{cases} VH(1-\eta_k/\eta_0) & \text{if } \eta_0 > 2\eta_k, \\ VH/2 & \text{if } 2\hat{\eta} \leqslant \eta_0 \leqslant 2\eta_k, \\ VH(1-\hat{\eta}/\eta_0) & \text{if } \hat{\eta} \leqslant \eta_0 < 2\hat{\eta}, \\ VH & \text{if } \eta_0 < \hat{\eta}. \end{cases} \tag{6}$$

Finally, substituting the price and user population into the profit function, we have the profit:

$$\pi_m^* = \begin{cases} \eta_k VH(1-\eta_k/\eta_0) - K(\eta_k) & \text{if } \eta_0 > 2\eta_k, \\ \eta_0 VH/4 - K(\eta_k) & \text{if } 2\hat{\eta} \leqslant \eta_0 \leqslant 2\eta_k, \\ \hat{\eta} VH(1-\hat{\eta}/\eta_0) - K(\eta_k) & \text{if } \hat{\eta} \leqslant \eta_0 < 2\hat{\eta}, \\ -K(\eta_k) & \text{if } \eta_0 < \hat{\eta}. \end{cases} \tag{7}$$

4.1.2. Choice of QoS level

In the above analysis, the service quality level H is assumed to be exogenous and proposed by the industry standard. If the market is not perfectly competitive, the service quality level should be one of the decision variables. From (7), we can straightforwardly observe that the revenue is positively related to the quality level. In order to maximize profit, the platform provider should improve its service quality as much as possible. However, higher quality desires larger subscribers and higher individual contributions, which requires the reduction of the price. The decision problem the platform provider faces is to choose an appropriate SLA that generates the maximum revenue. According to (7), given a service quality level $H = H'$ in which $\eta_0 \geqslant 2\hat{\eta}$, the platform provider can increase the quality to a level $H = H''$ such that condition $\eta_0 \leqslant 2\hat{\eta}$ is satisfied. Since the number of subscribers is still bounded by platform capacity, the objective function is reformulated as

$$\begin{aligned} \text{Max}_H \quad \pi_m &= \hat{\eta} VH(1-\hat{\eta}/\eta_0) - K(\eta_k) \\ &= \frac{\ln(1-H)}{\ln(1-\bar{h})} VH\left(1 - \frac{\ln(1-H)}{\ln(1-\bar{h})\eta_0}\right) - K(\eta_k) \\ \text{s.t.} \qquad &\hat{\eta} \leqslant \eta_k. \end{aligned} \tag{8}$$

We first derive the optimal service quality level under the condition that the capacity constraint is not binding, $\widehat{H}$, by solving $\partial\pi_m/\partial H = 0$. $\widehat{H}$ can be obtained from the following equation:

$$\frac{\ln(1-\bar{h})\eta_0 - 2\ln(1-H)}{(\ln(1-\bar{h})\eta_0 - \ln(1-H))\ln(1-H)} = \frac{1-H}{H}. \tag{9}$$

Proposition 2. *For a monopolistic service provider offering a single service class, the optimal SLA contract is developed as*

$$SLA(H_m^*, p_m^*) = \left(\min\left(1-(1-\bar{h})^{\eta_k}, \widehat{H}\right), VH_m^*(1-\eta_m^*/\eta_0)\right),$$
$$\text{where}\quad \eta_m^* = \min\left(\eta_k, \frac{\ln(1-\widehat{H})}{\ln(1-\bar{h})}\right). \tag{10}$$

Inevitably the QoS is restricted by the number of participants. Price can be used to adjust the number of participants but the maximum QoS is still limited by the platform capacity. Therefore, the importance of capacity planning cannot be overemphasized.

4.1.3. Choice of capacity investment

The above QoS choice is evaluated after the infrastructure has been constructed. The capacity is treated as an exogenous parameter as in a short run; we cannot adjust the capacity. In a long run, capacity planning can be considered and capacity becomes an endogenous variable. To avoid unused capacity, the platform provider will choose the capacity that just equals the subscription demand ($\eta_k = \hat{\eta}$). The decision problem is rewritten as

$$\text{Max}_{\eta_k}\pi_m = \eta_k VH(1-\eta_k/\eta_0) - K(\eta_k). \tag{11}$$

Let $\hat{\eta}_k$ be the optimal capacity that maximizes profit. $\hat{\eta}_k$ is given by solving $\partial\pi_m/\partial\eta_k = 0$, or

$$\left((1-2\eta_k/\eta_0)(1-(1-\bar{h})^{\eta_k}) - \ln(1-\bar{h})(1-\bar{h})^{\eta_k} \times \left(\eta_k - \eta_k^2/\eta_0\right)\right)V - K'(\eta_k) = 0. \tag{12}$$

Notice that if $\pi_m < 0$, then $\hat{\eta}_k$ becomes zero and no service will be provided.

4.2. Multiple service classes

Now, we analyze the scenario in which multiple service levels are offered. Assume the platform provider offers two classes of service quality level: a high class of service with quality level H_h and price p_h, and a low class of service with quality level H_l and price p_l. The utility function of user i subscribing to class q is $U_i = v_i H_q - p_q$ where $q \in Q = \{h,l\}$. The customers choose a better service to subscribe to if his/her utility $U_i \geqslant 0$. Let $\hat{v}_1$ be the value of a marginal user who is indifferent between taking services from the two SLAs. $\hat{v}_1$ is given by $v_i H_h - p_h = v_i H_l - p_l$. Therefore, $\hat{v}_1 = (p_h - p_l)/(H_h - H_l)$. Users with a higher valuation of the service should prefer a high-quality service. However, users with a lower valuation prefer a low-quality service whenever he/she can receive a non-negative utility. Let $\hat{v}_2$ be the value of a marginal user who can achieve a non-negative utility from subscribing to a low-quality service. We have $\hat{v}_2 H_l - p_l \geqslant 0$, or $\hat{v}_2 \geqslant p_l/H_l$. Therefore, users $v_i \in [\hat{v}_1, V]$ subscribe to the high-quality class but users with $v_i \in [\hat{v}_1, \hat{v}_2]$ will subscribe to the low-quality service. The users whose valuation of the service is too low $v_i \in [0, \hat{v}_2]$ will never subscribe to any class of service. Consequently, we have a subscription demand of two service classes:

$$\eta_h = \left(1 - \frac{p_h - p_l}{V(H_h - H_l)}\right)\eta_0, \quad \eta_l = \left(\frac{p_h - p_l}{V(H_h - H_l)} - \frac{p_l}{VH_l}\right)\eta_0. \tag{13}$$

Given the two classes of the SLA scheme and the corresponding capacity η_{kh} and η_{kl}, the pricing decision problem can be formulated as

$$\text{Max}_{p_h,p_l}\pi_m^{h+l} = p_h\eta_h + p_l\eta_l - K(\eta_{kh}) - K(\eta_{kl}). \tag{14}$$

Solving $\partial\pi_m^{h+l}/\partial p_h = 0, \partial\pi_m^{h+l}/\partial p_l = 0$, we have $p_h^* = VH_h/2$, $p_l^* = VH_l/2$. The subscription demand can be obtained as $\eta_h^* = \eta_0/2, \eta_l^* = 0$. The result shows that the platform will never offer multiple classes of service and only a high-quality service is provided.

Proposition 3. *A monopolistic provider never provides multiple differentiated SLA contracts.*

The result mainly comes from the significant externality effect of the users on the service quality and the effect overweighs the market segmentation effect. Therefore, a better business strategy for a monopolistic provider is to offer single class of service as developed. In reality, at the time when there were no other competitors, Experts-Exchange and Mininova provided two types of service. Basic service allowed users to access limited contents (low quality), whereas premium service can search whole website database (high quality). But due to the nature of peer production, it is hard to control the contribution of self-organized participants and make two types of service quality feasible. After running for a period of time, basic service was revoked. This phenomenon is consistent with Proposition 3, implying that service differentiation of peer-produced service in a monopolistic market is infeasible.

5. Duopolistic market

In this section, we extend our model to discuss the quality and price competition of two independent service providers. The scenario that both platform providers conduct price competition for providing identical SLA contracts is first discussed. Then, heterogeneous SLA contracts are provided by the two competing platform providers. First, we consider that there are two identical symmetric service providers.

5.1. Homogeneous SLA contract

5.1.1. Choice of SLA contract

As the service quality levels of the two systems are identical, users always choose the cheaper one. For the sake of price competition, the providers will reduce their price to attract the users from their opponent. The number of subscriptions is increasing as the competing service providers continue to drop their price. The process will not cease until one of two situations occurs: the number of subscriptions reaches the capacity limit of the infrastructure or the providers make no profit. In the first scenario, both competing providers received non-negative profit. The price and the number of subscribers are

$$p_c^* = VH(1-2\eta_k/\eta_0) \quad \text{and} \quad \eta_c^* = \eta_k. \tag{15}$$

In the second scenario, if the capacity is large enough, the process of price undercutting continues. Finally, the price declines just to cover the investment cost and both providers make no profit. The price and subscription demand become

$$p_c^* = \frac{1}{2}\left(VH - \sqrt{(VH)^2 - 8K(\eta_k)VH/\eta_0}\right) \quad \text{and}$$
$$\eta_c^* = \frac{\eta_0}{2}\left(\frac{1+\sqrt{1-8K(\eta_k)/(VH\eta_0)}}{2}\right). \tag{16}$$

The equilibrium price exists only if $\frac{(VH)\eta_0}{8} \geqslant K(\eta_k)$. If two competing providers offer identical SLA contracts, the contract is given by

$$SLA(H_c^*, p_c^*) = \left(\min(H_k, \widehat{H}), \max\left(VH_k(1-2\eta_k/\eta_0), \times\frac{1}{2}\left(V\widehat{H} - \sqrt{(V\widehat{H})^2 - 8K(\eta_k)V\widehat{H}/\eta_0}\right)\right)\right), \tag{17}$$

where $H_k = 1-(1-\bar{h})^{\eta_k}$ and $\widehat{H}$ is a solution of

$$\frac{\ln(1-H)}{\ln(1-\bar{h})} = \frac{\eta_0}{4}\left(1+\sqrt{1-8K(\eta_k)/(VH\eta_0)}\right). \tag{18}$$

And each provider receives profit

$$\pi_c^* = \max(\eta_k VH_k(1-2\eta_k/\eta_0) - K(\eta_k), 0). \tag{19}$$

Proposition 4. *For homogeneous service providers, higher capacity may improve the QoS but is never beneficial to homogeneous providers because of higher intensive competition. Furthermore, both providers receive zero profit if the capacity is higher than specific threshold.*

In reality, Experts-Exchange and Google Answers provided comparable service quality to the public. Google Answers started with small capacity and was very popular (West, 2002). It was full of users and very busy and Google did make profit. Thus Proposition 4 is evidenced when the demand is limited by the capacity. Similar scenario can also be observed in P2P resource sharing service providers like Pirate Bay and Mininova.

5.1.2. Choice of capacity investment

In a long run, providers set up an appropriate capacity investment to ensure a non-negative profit. The profit function for each platform provider is written as

$$\text{Max}_{\eta_k}\pi_c = \eta_k VH(1-2\eta_k/\eta_0) - K(\eta_k). \tag{20}$$

Let $\hat{\eta}_k$ be the optimal capacity that maximizes profit. $\hat{\eta}_k$ is given by solving $\partial\pi_m/\partial\eta_k = 0$, or

$$\left((1-4\eta_k/\eta_0)(1-(1-\bar{h})^{\eta_k}) - \ln(1-\bar{h})(1-\bar{h})^{\eta_k}(\eta_k - 2\eta_k^2/\eta_0)\right)V - K'(\eta_k) = 0. \tag{21}$$

Notice that if $\pi_c < 0$, then $\hat{\eta}_k$ becomes zero and no service will be provided. Comparing (12) and (21), we can find that the levels of the capacity and service quality in a competing market are smaller than in a monopolistic market.

5.2. Heterogeneous SLA contracts

Next, we consider two competing providers offering heterogeneous SLA contracts with high quality H_h and low quality H_l, respectively.

5.2.1. Choice of SLA contract

The timing of the game stage is as follows. In the first stage, the competitive providers choose the quality level simultaneously; in the second stage, the providers choose the price for their service simultaneously. Finally, after observing the SLA contract, the customers choose a better service if $U_i \geqslant 0$. From (13), the profit function of the providers is written as

$$\begin{aligned}\pi_h &= p_h\left(1 - \frac{p_h - p_l}{V(H_h - H_l)}\right)\eta_0 - K(\eta_{kh}),\\ \pi_l &= p_l\left(\frac{p_h - p_l}{V(H_h - H_l)} - \frac{p_l}{VH_l}\right)\eta_0 - K(\eta_{kl}).\end{aligned} \tag{22}$$

Solving $\partial\pi_h/\partial p_h = 0$ and $\partial\pi_l/\partial p_l = 0$ simultaneously, we obtain the price strategy

$$p_h = \frac{2VH_h(H_h - H_l)}{4H_h - H_l}, \quad p_l = \frac{VH_l(H_h - H_l)}{4H_h - H_l}. \tag{23}$$

Also, the profit can be induced as

$$\begin{aligned}\pi_h &= \frac{4VH_h^2(H_h - H_l)}{(4H_h - H_l)^2}\eta_0 - K(\eta_{kh}),\\ \pi_l &= \frac{VH_lH_h(H_h - H_l)}{(4H_h - H_l)^2}\eta_0 - K(\eta_{kl}).\end{aligned} \tag{24}$$

Since $\partial\pi_h/\partial H_h > 0$, the best response quality strategy of the high service provider is to set the quality as high as possible, calculating his opponent's strategy. The best response quality strategy of the provider with a lower quality level can be obtained by solving $\partial\pi_l/\partial H_l \geqslant 0$. Here, we have $H_l^* = \phi H_h$, where $\phi \leqslant 4/7$ and the price can thus be obtained as

$$p_h = \frac{2VH_h(1-\varphi)}{4-\varphi}, \quad p_l = \frac{VH_l(1-\varphi)}{4-\varphi}. \tag{25}$$

The demand for a high- and low-quality service can be obtained as

$$\begin{cases}\eta_h = \frac{2\eta_0}{4-\phi} \\ \eta_l = \frac{\eta_0}{4-\phi}\end{cases} \text{if } H_l \neq 0, \quad \begin{cases}\eta_h = \frac{\eta_0}{2} \\ \eta_l = 0\end{cases} \text{if } H_l = 0. \tag{26}$$

Similarly, the profits for the two providers with differentiated service quality can be obtained as

$$\pi_h = \frac{4VH_h(1-\varphi)\eta_0}{(4-\varphi)^2} - K(\eta_{kh}), \quad \pi_l = \frac{VH_l(1-\varphi)\eta_0}{(4-\varphi)^2} - K(\eta_{kl}). \tag{27}$$

From (27), we know that both service providers will set their quality as high as possible, satisfying the condition $H_l^* = \phi H_h$. ϕ is constrained by the capacity of the providers and the size of the potential market. As $\eta_h \leqslant \eta_{kh}$ and $\eta_l \leqslant \eta_{kl}$, we have $\varphi \leqslant \varphi_k = \max(4 - \eta_0/\min(\eta_{kh}/2, \eta_{kl}), 0)$. In addition, the demand for each type of service will be sufficiently large to ensure the SLA advertised. $\sigma = (1-(1-\bar{h})^{\eta_l})/(1-(1-\bar{h})^{\eta_h})$ denotes the ratio of the actual lower quality level to the higher one. It can be easily verified that $\partial\sigma/\partial\phi < 0$. Since the service providers can advertise their service with a quality level not larger than the actual quality level and the high-quality provider can set his/her quality as high as possible regardless of the level of the lower quality one, we have $\phi \leqslant \phi_\eta$, where ϕ_η is the value of ϕ that satisfies $\phi = \sigma$. Finally, we obtain the equilibrium SLAs for both providers:

$$H_h = 1 - (1-\bar{h})^{\eta_h}, \quad H_l = \varphi H_h, \quad \text{where} \quad \varphi = \min(4/7, \varphi_k, \varphi_\eta). \tag{28}$$

Finally, these *heterogeneous SLA contracts* $SLA(H_h^*, p_h^*)$ and $SLA(H_l^*, p_l^*)$ are described in Eqs. (25) and (28).

Proposition 5. *If two competing service providers offer heterogeneous SLA contracts,*

(i) *the demand, price, and profit of high-quality service are more than those of low quality;*
(ii) *the low-quality provider advertises a lower SLA than he/she can actually offer.*

As Proposition 5 suggests, the low-quality provider should advertise a lower SLA than he/she can actually offer. By doing this the users enjoy higher quality than advertised, and a sufficient number of users required to maintain SLA is kept. Thus the low-quality provider can compete with its opponent and sustain. Evidence can be observed from the competition of Pirate Bay and Torrentz. The former one is the leading company while the latter one provides lower quality of service. But the resources found in Torrentz are more than expected, which makes its subscribers enjoy better quality. By advertising a lower SLA, Torrentz maintains sufficient subscribers and survives in the competition with Pirate Bay.

5.2.2. Choice of capacity investment

In a long run, the providers can choose appropriate capacity investment to improve their profit level. In order to utilize the platform fully, the providers will choose a capacity level of the platform equaling the actual subscription demand. That is,

$$\eta_{kh} = \eta_h = \frac{2H_h\eta_0}{4H_h - H_l}, \quad \eta_{kl} = \eta_l = \frac{H_h\eta_0}{4H_h - H_l}. \tag{29}$$

Because the capacity levels of two platforms, η_{kh} and η_{kl}, become functions of the H_h and H_l, the objective function of the two providers can be written as

$$\begin{aligned} &\text{Max}_{H_h} \quad \pi_h = \frac{4VH_h^2(H_h - H_l)}{(4H_h - H_l)^2}\eta_0 - K(\eta_{kh}), \\ &\text{s.t.} \qquad H_h \leqslant 1 - (1-\bar{h})^{\eta_{kh}}. \end{aligned} \tag{30}$$

$$\begin{aligned} &\text{Max}_{H_l} \quad \pi_l = \frac{VH_lH_h(H_h - H_l)}{(4H_h - H_l)^2}\eta_0 - K(\eta_{kl}), \\ &\text{s.t.} \qquad H_l \leqslant 1 - (1-\bar{h})^{\eta_{kl}}. \end{aligned} \tag{31}$$

Without regarding the advertised quality agreement, the high-quality platform provider's best response function $\widehat{H}_h^*(H_l)$ is given by solving $\partial\pi_h/\partial H_h = 0$, which can be rewritten as

$$\begin{aligned} &\frac{4\left(\widehat{H}_h^*(H_l)\right)^2 - 3\widehat{H}_h^*(H_l)H_l + 2H_l^2}{4\widehat{H}_h^*(H_l) - H_l} \cdot 2V\widehat{H}_h^*(H_l) \\ &\quad + K'\left(\frac{2\widehat{H}_h^*(H_l)\eta_0}{4\widehat{H}_h^*(H_l) - H_l}\right) \cdot H_l = 0. \end{aligned} \tag{32}$$

However, if the advertised quality cannot be satisfied, the high-quality platform provider has to refine its advertised quality to satisfy the SLA. Hence, its best response function $\widetilde{H}_h^*(H_l)$ is given by solving $H_h = 1 - (1-\bar{h})^{\eta_{kh}}$ when the case arises, which can be rewritten as

$$\frac{\left(4\widetilde{H}_h^*(H_l) - H_l\right)\ln\left(1 - \widetilde{H}_h^*(H_l)\right)}{2\widetilde{H}_h^*(H_l)} = \ln(1-\bar{h})\eta_0. \tag{33}$$

As a result, the high-quality platform provider's best response function is given by

$$H_h^*(H_l) = \begin{cases} \widehat{H}_h^*(H_l), & \text{if } \widehat{H}_h^*(H_l) \leqslant 1 - (1-\bar{h})^{\eta_{kh}}, \\ \widetilde{H}_h^*(H_l), & \text{if } \widehat{H}_h^*(H_l) > 1 - (1-\bar{h})^{\eta_{kh}}. \end{cases} \tag{34}$$

Similarly, the low-quality platform provider's best response function is given by

$$H_l^*(H_h) = \begin{cases} \widehat{H}_l^*(H_h), & \text{if } \widehat{H}_l^*(H_h) \leqslant 1 - (1-\bar{h})^{\eta_{kl}}, \\ \widetilde{H}_l^*(H_h), & \text{if } \widehat{H}_l^*(H_h) > 1 - (1-\bar{h})^{\eta_{kl}}, \end{cases} \tag{35}$$

where $\widehat{H}_l^*(H_h)$ is derived from solving $\partial\pi_l/\partial H_l = 0$, or (36), and $\widetilde{H}_l^*(H_h)$ is derived from solving $H_l = 1 - (1-\bar{h})^{\eta_{kl}}$, or (37).

$$\frac{H_h\left(4H_h - 7\widehat{H}_l^*(H_h)\right)}{4H_h - \widehat{H}_l^*(H_h)}V + K'\left(\frac{H_h\eta_0}{4H_h - \widehat{H}_l^*(H_h)}\right) = 0, \tag{36}$$

$$\frac{\left(4H_h - \widetilde{H}_l^*(H_h)\right)\ln(1 - H_h)}{2H_h} = \ln(1-\bar{h})\eta_0. \tag{37}$$

Finally, solving $H_h^*(H_l)$ and $H_l^*(H_h)$ simultaneously yields Nash equilibrium solution H_h^* and H_l^*, and each provider's capacity is given by substituting H_h^* and H_l^* into (29).

6. Numerical results

In this section, we present numerical results to illustrate the SLA contract and profit levels under different market structures. In a short run, the capacity cannot be changed and is treated as an exogenous parameter. However, in a long run, the platform provider can choose the appropriate capacity to improve profit. Hence, capacity becomes an investment decision variable. Thus, in the short-term condition, we depict the impacts of predefined platform capacity, whereas we investigate the impact of market size on the SLA contract and capacity investment in the long-term section. Following economic literatures (Gilbert and Weng, 1998; Iyer, 1998; Jaisingh, 2009), capacity function is assumed to be a convex function on the maximum number of users allowed. For demonstration, the capacity cost function is quadratic (Cachon and Zhang, 2007) and defined as $K(\eta_k) = \lambda\eta_k^2$, where λ is a non-negative constant and η_k is the number of users the service platform can serve. The parameter for investment function is $\lambda = 0.000001$. As peer production producing high-quality results from small contributions by numerous independent volunteers (Benkler, 2002; Benkler and Nissenbaum, 2006). So we assume the average contribution rate $\bar{h} = 0.00005$, which appropriately describes the characteristic of small individual contributions. The number of users and the capacity should be large. Therefore, in the short-term scenario, the number of potential users is $\eta_0 = 100{,}000$, and the capacity η_k ranges over 30,000–80,000 and $\eta_k = \eta_{kh} = 2\eta_{kl}$. For the long-term scenario, $\bar{h}$ and λ remain unchanged and η_0 ranges over 10,000–100,000.

6.1. Short-term scenario

6.1.1. Quality

From Fig. 1, it is observed that the service quality of the short-term scenario increases with capacity, except in homogeneous competing providers. For the monopoly provider (H_m) and homogeneous competing providers (H_c), if the capacity is not large enough to service the number of subscribers required to achieve optimal quality, the quality is bounded by capacity and both markets provide an identical service quality. If the capacity is large enough, H_m is kept but H_c decreases as the capacity increases. The intuition is because homogeneous providers compete with each other on price and the price undercutting continues. Finally, it declines to cover just the investment cost. The cost is increased with capacity and thus the price is also increased. However, a higher price results in fewer subscribers, and consequently the quality is decreased. As for heterogeneous competing providers, the optimal quality of the lower one is proportional to that of the higher one and the ratio is constrained by capacity. The ratio becomes zero if both capacities are low and H_l is set to 0. As both providers increase their capacity, the ratio also rises and is becoming closer to the optimal rate 4/7. Finally, both platforms can serve more than the optimal subscribers and the quality is fixed.

Observation 1. The effect of capacity on service quality of homogeneous competing providers is non-monotonic (positive if capacity is small but negative if large). However, in other market settings, the effect of capacity on service quality is always non-negative.

Competition generally results in a lower price and higher QoS. However, for homogeneous providers, intensive competition may force the providers set higher price to cover the investment as the capacity becomes sufficiently large. Consequently, users will

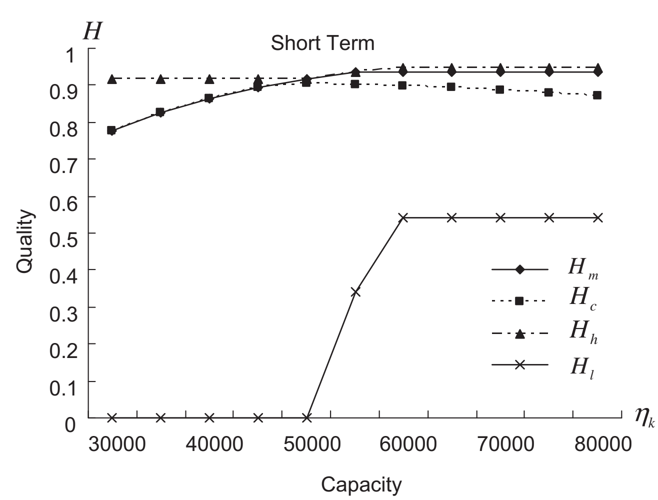

Fig. 1. Impact of capacity on service quality.

not be willing to subscribe because of high price and the service quality cannot be improved since there is no enough subscribers. As for the other market structures, the monopolistic provider serve only one type of quality, whereas the heterogeneous providers provide different service quality to different types of users. In these settings more users can be served by way of improving capacity and the service quality can be improved.

6.1.2. Price

Ideally, the service quality is increased with subscribers. Nevertheless, this condition holds only if there is no capacity constraint. If this is not the case, the quality will not increase with the number of subscribers after the capacity limit has been reached. In Fig. 2, for the monopoly provider (p_m), when the capacity is small, he/she sets a higher price to restrict the amount of subscribers. The price is then reduced to attract more users as the capacity increases until the optimal quality is reached, and the price is fixed. For the homogeneous competing providers (p_c), there is a bit different. Interestingly, the price first decreases and then increases. The reason for the decreasing part is the same as that of the monopoly provider, while the increasing part results from the effect of price competition and increasing capacity investment cost. If the capacity is large enough, the process of price undercutting won't stop until both providers make no profit. Then, the price has to cover their capacity investment cost to ensure they receive non-negative profit, and this is the reason the price increases with capacity. The effect of capacity on the price decision in two heterogeneous competing providers (p_h and p_l) could be in opposite directions. The price of a high-quality service (p_h) increases with the capacity when the capacity is small, because it improves the quality level. However, because of the emergence of a competing low-quality service, the price decreases with the capacity until the optimal quality is reached. After that, the price is a fixed value. In contrast, the price of a low-quality service (p_l) shows different result. In the beginning, the low-quality service is not provided since its quality is 0 and no price can be charged. The price is then increasing as the service quality keeps improving. Finally, the optimal quality level results in a fixed price.

Observation 2. The effects of capacity on price level with respect to various market settings are significantly different.

(1) The effect of capacity on the service price of a monopolistic provider is always non-positive. However, the effect of capacity on the service price of homogeneous providers is non-monotonic (negative if capacity is small but positive if large).

(2) The effect of capacity on the service price of the high quality provider is non-monotonic (positive if capacity is sufficiently small or large but negative if in some middle interval). However, the effect of capacity on the service price of the low-quality provider is always non-negative.

Overloading occurs when the capacity is small, thus the monopolistic provider utilizes price as a controlling tool to avoid this problem. For heterogeneous providers with small capacity, the high-quality provider can set a higher price since the opponent can not commit the SLA because of the shortage of users. But by providing more capacity the low-quality provider can service more users and thus the SLA can be committed. To maintain the service quality the high type provider has to lower the price to keep a sufficient number of users to guarantee the quality advertised.

6.1.3. Profit

From Fig. 3, we observed that all the profit levels decrease as the capacity becomes large enough because of the convexly increasing capacity cost. For the monopoly provider (π_m), increasing profit accompanies increasing quality if the optimal quality is not reached. After that, since the price is fixed by optimal quality, the profit is then corroded by capacity investment. For the homogeneous competing providers (π_c), both make profit when capacity is small. The price-cutting process forces them to set the price just to cover the capacity cost as capacity increases and finally results in zero profit.

As for the high-quality provider (π_h), the price always decreases with the capacity, whereas the low-quality provider (π_l) receives negative profit when capacity is small, then has increasing profit as the capacity becomes larger until the optimal quality is reached. After that, the profit is corroded by the capacity cost. If the capacity is too small for heterogeneous providers, as Fig. 1 shows, the low-quality one cannot provide any service since its quality is zero. On the other hand, the service quality is bounded by capacity for the high-quality one. Moreover, as observed from Fig. 3, the increase in capacity helps the low-quality provider to receive non-negative profit. Thus, both providers provide more capacity to improve the quality.

Observation 3. The effects of capacity on profit level with respect to various market settings are significantly different.

(1) The effect of capacity on the profit of a monopolistic provider is non-monotonic (positive if capacity is small but negative if large). However, the effect of capacity on the profit of homogeneous providers is always non-positive.

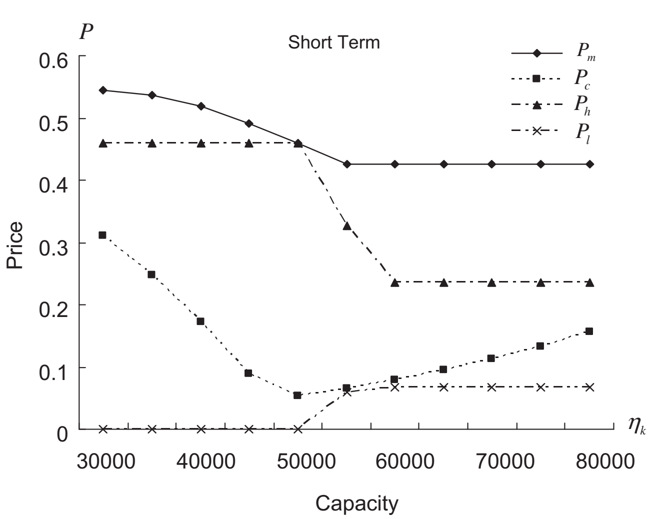

Fig. 2. Impact of capacity on price.

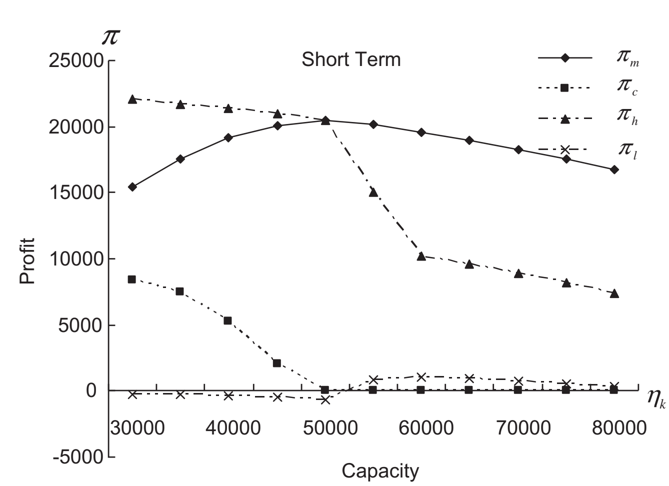

Fig. 3. Impact of capacity on profit.

(2) The effect of capacity on the profit of the high-quality provider is always negative. However, the effect of capacity on the service price of the low-quality provider is non-monotonic (negative if capacity is sufficiently small or large but positive if in some middle interval).

The emphasis of peer-produced service is on the power of community and network externality. Ideally, the more participants, the better the service quality; however, the quality is bounded by the installed capacity and capacity investment is costly. For a monopolistic provider, balancing the capacity investment and service quality is the main issue, which inherently should be resolved in a long-term scenario. The impact of capacity on the profit of homogeneous competing providers is always negative as a larger capacity only results in higher competition. The capacity effect on the profit of the low-quality provider is similar to that of the monopolistic provider. However, the high-quality provider has less incentive to expand its capacity. As we can observe, homogeneous competing providers receive higher profit than low-quality providers. That is, only the high-quality provider benefits from differentiation.

6.2. Long-term scenario

As observed from Figs. 4–7, in the long run, all the providers provide increasing service quality and receive more profit as the potential user population (market size) grows. However, the market size does have an impact in some ways. When the market size is small, we can find that the monopoly provider provides higher quality and establishes larger capacity than the high-quality provider. The low-quality provider serves users with higher quality and larger capacity than homogeneous providers. Although the quality ranks in third place for the low-quality provider, he/she charges the lowest price. If the market size is large enough, the monopoly provider would provider lower quality than the high-quality one, but homogeneous providers are better than that of the low-quality one. However, from Fig. 6, we know that the low-quality provider does not invest less in capacity than homogeneous providers even if the quality is not as good as theirs. As for the price, the homogeneous providers charge more than the high-quality provider even though they do not provide better quality.

6.2.1. Discussion (the role of market size)

In a large market, the high-quality provider establishes the largest capacity and provides the highest service quality, but does not

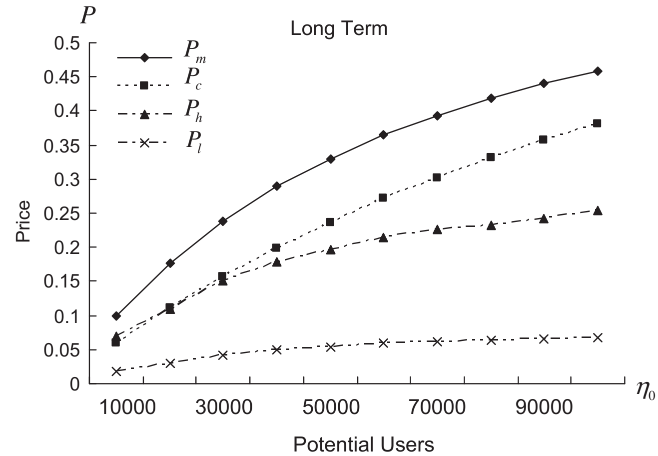

Fig. 5. Impact of market size on price.

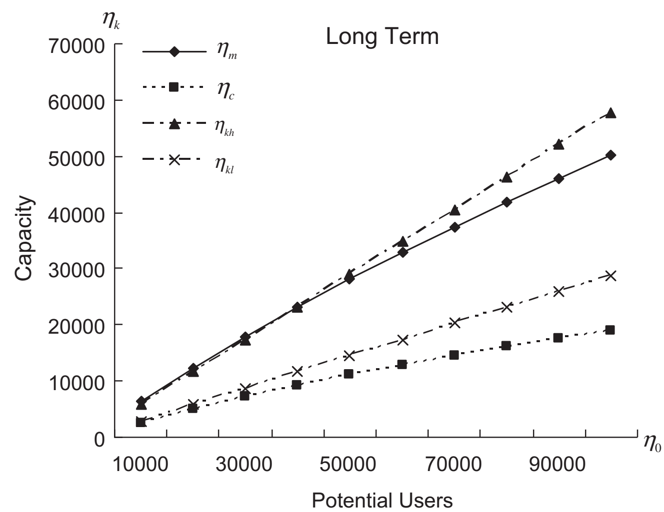

Fig. 6. Impact of market size on capacity.

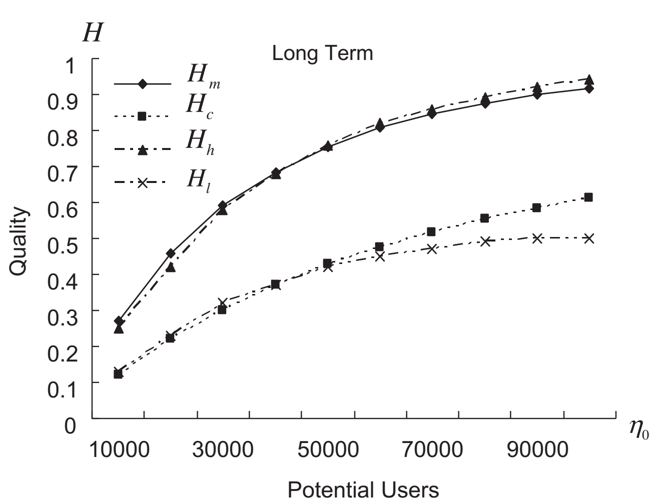

Fig. 4. Impact of market size on service quality.

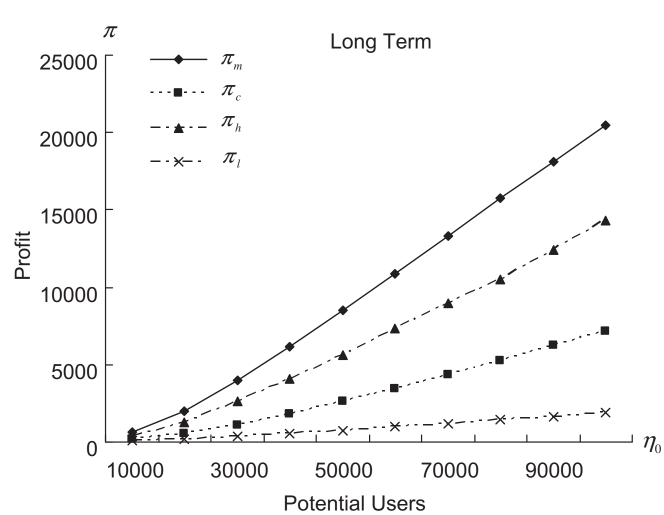

Fig. 7. Impact of market size on profit.

charge the highest price. In contrast, the monopoly market sets the highest price and receives the highest profit. The homogeneous competing providers set up the smallest capacity, but charge a good price even though the quality is not good enough. The low-quality provider invests in capacity greater than that of homogeneous providers, but the quality, price, and profit rank the lowest. In a small market, the quality of competitive markets (homogeneous and heterogeneous) is lower than the monopoly market. From the viewpoint of potential users, they can enjoy high-quality contents from differentiated services if the market size is large enough.

7. Managerial implications

Our research provides useful insights for developing business strategies of peer-produced services to enhance the profit of a platform provider under various market settings. From our analytical and numerical findings, we have several implications, described as follows, for those who intend to operate peer-produced service platforms.

First, SLA based contracts for peer-produced services can be feasibly deployed. While service quality level of peer-produced service is uneasily to be measured because of uncertain individual contribution, we show that it is possible to obtain the lower bound of service quality. When service quality information is available, users would also benefit from choosing the appropriate service as needed and the service provider can further develop SLA based service pricing schemes. Second, although product versioning or differentiation is a popular business strategy for profitability improvement, our results reveal it is infeasible for a monopolistic peer-produced service provider. The phenomenon mainly comes from there exists significant positive externality on the peer-produced services. Furthermore, in a duopolistic market, the benefit from service differentiation becomes effective only when the population of users is sufficiently large. Third, the effect of the critical mass should be considered in a competition market. According to our findings, for a low-quality provider in a heterogeneous competition environment, only when the number of users reaches the critical mass will it make profit. Besides, by maintaining the users to ensure the suitable quality, the low-quality provider can differentiate itself from the high-quality one. Therefore, the provider positioned as a low-quality service provider should focus its strategy on attracting the critical mass. However, it would not be necessary to control the contributions of users. Since the heterogeneity of users help improve the quality of peer-produced service (Stvilia et al., 2008), service providers can focus on attracting users rather than filtering individual contribution rate. Fourth, understanding the market structure and position is essential before investment. The same capacity would have very different impacts on quality, price and profit in various market structures. Intuitively, the providers should attract as many users as possible by building up sufficient large capacity. If a service provider expands capacity unceasingly, the result could possibly have exactly opposite effect. A duopolistic market, even when offering identical service quality level, each competing provider can still receive non-negative profit. For the homogeneous competitors, the profit will be corroded completely if they have to raise the price to cover the capacity cost. Consequently, no profit can be gained. These imply that if a company plans to operate a service platform, by understanding the competitors in the market a better investment decision can be made.

8. Conclusions

Pricing based on SLA have become increasingly promising in IT related services. Peer-produced services are a new types of services in which service quality is determined by the participants. While the service platform providers do not need to provide the service, the quality is uncertain. Guaranteed service quality level is an essential component for SLA based pricing. In this research, we show that an SLA lower bound can be obtained by simply measuring the average contribution rate of participants. We utilize a game theoretical approach to study price, quality and capacity decisions of service providers. SLA based pricing strategies and capacity investments under various market structures can be further developed. The proposed approach can feasibly used to support the operations of peer-produced services.

Our results show that in a monopolistic market, the service provider should provide only single SLA since no users would subscribe to low quality service. For a competitive market with homogeneous providers, the market is equally divided and both providers can make profit constrained by capacity, or make no profit because of competition. As a result, their profits decrease with the capacity. For a market with heterogeneous providers, the demand, price, and profit of high-quality service are more than those of low quality and the low-quality provider advertises a lower SLA than he/she can actually offer. In addition to the market structure, capacity plays a significant role in developing service quality and pricing strategy. In most of the marketing settings, the service quality increases as the capacity becomes larger; however, the result could be opposite in a market with homogeneous providers. For a monopolistic provider, a higher capacity never raises the service price of a monopolistic provider. However, the effect of capacity on the service price of homogeneous providers or a high-quality provider is non-monotonic. Contrary to other scenario, a higher capacity will generally raise the service price of a low-quality provider.

The main unique contributions of this study are as follows From the theoretic perspective, this paper utilizes reliability model based on a simple average contribution rate to measure the lower bound SLA, which conquer the quality uncertainty of peer-produced service and incorporate game theory optimization model develop competition models with quality and capacity constraints in the context of peer-produced services. From the practical perspective, our research suggests a feasible business model (SLA based pricing and competition strategy) to support the operations of peer-produced services. Various market structures are investigated to completely reveal the business model, and managerial implications are provided to practitioners for better decision making.

There are several directions for future research. First, the average contribution rate is used to set the lower bound of the SLA, but the mechanism of measuring is not explicitly discussed. Second, the individual contribute rate is treated as an exogenously random variable; the incentive for contribution can be further developed as the quality is directly associated with the contribution rate. Third, the participants and contribution rate change from time to time. It would be valuable to study the dynamic SLA mechanism and pricing strategies. Finally, in addition to the resource availability, the service quality evaluation can be extended to include more performance factors, such as resource freshness and popularity and retrieval delay.

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