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*Service Co-Production, Customer
Efficiency and Market Competition*

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03-03





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*The Working Paper Series is made possible by a generous
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Service Co-production, Customer Efficiency and Market Competition¹

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Abstract

Customers' participation in service co-production processes has been increasing with the rapid development of self-service technologies and business models that rely on self-service as the main service delivery channel. However, little is known about how the level of participation of customers in service delivery processes influences the competition among service providers. In this paper, a game-theoretic model is developed to study the competition among service providers when self-service is an option. The analysis of the equilibria from this model shows that, given a certain level of customer efficiency, the proportion of the service task outsourced to the customer is a decisive factor in the resulting competitive equilibria. In the long run, two extreme formats of service delivery are expected to prevail rather than any mixture of both: either complete employee service or complete self-service. In the two-firm queuing game, we find that both firms are better off when they both deliver their service through self-service. It is also shown that full-service providers dominate the market if firms providing service products featuring self-service fail to have enough market demand at a profitable price. Meanwhile, the limited ranges of customer efficiency and the price for the self-service-only product are shown to be essential conditions for the coexistence of the different types of service providers.

¹This research was supported by the research grants from the Marketing Science Institute and the Wharton E-Business Initiative Research Center. The authors thank Gerard P. Cachon, Noah F. Gans, Lorin M. Hitt, and David J. Reibstein for their many valuable comments.

1 Introduction

Customers' involvement is generally indispensable for the completion of service production and delivery processes, although the degree of involvement varies from service product to service product. In some cases, customers provide only minimal assistance and remain passively involved throughout the process. In other cases, customers play more active roles by substituting employee service with their self-service. In recent years, the development of so-called self-service technologies have enabled customers' role transitions from passive involvement to active self-service in many industries. Many new business models aimed at utilizing customer self-service have appeared and have succeeded in establishing a market position and gaining market share, such as Internet banking, Internet brokerage, and Internet auctions. It is of interest from both an academic and practitioner viewpoint to study the competition between the newly emerging self-service-based service providers and the more traditional, employee-service-based service providers. Examples of such competition include the competition between the newly emerging Internet stock trading companies that have customers trading stocks and the traditional brokerage companies that have their employees trade stocks for the customers.

Though many factors may influence the outcome of such a competition, the distribution of the workload between the firm and the customer, or the self-service level, is clearly a decisive factor. First, the different level of self-service, or the different proportion of the workload outsourced to the customer, often means significant differences in terms of a firms' service delivery process, infrastructure, and costs. Secondly, the level of self-service defines the scale and scope of the impact of customers' participation on service quality. As customer self-service constitutes a significant part of the service, her own productivity or efficiency (customer efficiency) is also expected to have a certain influence on service quality and demand.

Consequently, customers' increasing participation in service co-production processes is also expected to bring changes in a competitive market: how will the newly emerged service firms that sell service products featuring self-service compete against the traditional service providers who offer more employee-based service delivery? Will the self-service firms ever be able to gain enough market share from the traditional service providers to survive? Will they prevail and drive the traditional employee service firms out of the market? Will the two types coexist in the market? More fundamentally, when should a firm choose to provide a self-service product and when to provide an employee-based service product? What are the implications of the results of this competition on the design of firms' service delivery processes, infrastructures, and costs? Should firms choose the extreme format of service delivery, either complete self-service or complete employee service (full-service), or a mixture of the two? What are the advantages and disadvantages of each alternative and how can their choices influence the outcome of the market competition?

In addition, what are the customers' roles in such a market competition? Traditionally, customers influence the outcome of market competition through their influence on market demand. Increasingly, customers can also influence competition as co-producers. How will customers' multiple influences on not only demand but also cost and quality affect the competitive outcome?

To address these issues in this paper, we investigate the role of self-service and customer efficiency in market competition when service co-production is involved. In particular, given a certain level of customer efficiency, we study how the level of self-service, or the distribution of the workload between the customer and the firm, influences firms' competitive strategies and the resulting market equilibria. To accomplish this analysis, we use a two-firm queuing game model in which the firms compete with each other in a single service product market. We consider a simplified situation where any proportion of the service task can be accomplished by either the firm's employees or by the customer. That is, we assume that any proportion of the service job can be outsourced to the customer. This assumption generally holds as long as the service task is not too complicated or does not require highly professional, specialized skills. In fact, even when a service delivery requires professional expertise, there is always certain part of it that can be or has to be completed by the customer (e.g., providing certain information needed for customization, billing, and shipping).

With the queuing game model, we show that in the long-run, the optimal proportion of the workload completed through self-service is either 0% or 100%. In fact, setting the self-service level at a certain value between zero and 100% can actually minimize a firm's profit. This is an interesting theoretical finding in that it predicts that the two extreme formats of service delivery, complete self-service and full-service, will prevail and that an intermediate solution will not be optimal.

We also find that an equilibrium in which both firms require all the service to be completed through self-service is the most profitable for both firms in a two-firm game, despite the fact that the two firms actually charge the lowest explicit price for the service product in such a (self-service, self-service) equilibrium.

More importantly, even though the higher profits of a (self-service, self-service) equilibrium may result from substituting generally more costly employee service with less costly self-service, we find that the existence of the most profitable (self-service, self-service) equilibrium relies on the prevention of downstream price cuts, which is actually realized through completely outsourcing the service task to the customer. The existence of the (self-service, self-service) equilibrium requires the explicit price for the self-service-only service product to be higher than a certain threshold. With economies of scale present, firms may attempt to cut prices in order to increase the demand and lower the average cost. As a result, it is not guaranteed that the price of the self-service-only product will not become lower than the threshold. However, by outsourcing the service task to the customer completely, each firm faces constant returns to scale instead of economies of scale, which

makes further demand-increasing price cut as an attempt to increase the demand and lower the average cost unnecessary and therefore prevents the downstream price cut that may endanger the existence of the (self-service, self-service) equilibrium.

In addition, we find that (full-service, full-service) can prevail only if the self-service-only business model doesn't manage to charge a high enough price in order to generate a sufficient profit margin. This may explain at least partially why many self-service business models that appeared during the e-commerce boom later failed to survive in markets dominated by full-service providers. The lack of customers' willingness to pay a certain price for self-service products, or the demand of the customers to be compensated for the self-service they contribute, undermines those firms' ability to generate enough market demand at a profitable price.

Furthermore, we find that self-service-only firms and full-service firms can coexist in equilibrium if customers aren't either highly efficient or highly inefficient, and the explicit price for the self-service-only product is neither too high or too low. This finding may help to explain the coexistence of both types of service providers in many service industries. Customers' medium level of efficiency makes the existence of both service channels feasible. The price of the self-service product is neither cheap enough to drive the full-service provider out the market, nor expensive enough to prevent the self-service firms from grabbing market share from the full-service provider.

In Section 2 we review the related literature. The model is described in Section 3 and the game is discussed in Section 4. The results are discussed in Section 5 along with the existing limitations and potential extensions.

2 Literature Review

Our work is related to three main streams in the service operations management literature. The first stream considers the influence of customer's participation and choice-making on a service operation. The second stream involves the extensive literature on queuing games. The third group includes works in outsourcing and vertical integration in operations management as well as in economics and marketing.

First, some previous works have been devoted to the study of customers' participation in service operations processes from different perspectives. Chase (1978) discusses customers' involvement in service operations and its potential influence on the service delivery process. Lovelock and Young (1979) suggest that customers' participation can help a firm to increase its productivity with appropriate design of self-service interfaces. Mills and Morris (1986) discuss the "partial" employee roles that customers have been playing in some service organizations by undertaking part of the workload. Karmarkar and Pitbladdo (1995) provide a comprehensive literature review on service

markets and competition and point out that an important research topic is understanding how a customer's engagement in service delivery processes will influence the design of the process as well as competition in the market. Heskett, Sasser, and Schlesinger (1997) suggest that by encouraging customers to share responsibility, firms can not only reduce their costs but also improve service quality. Xue and Harker (2002) discuss the potential impact of customers' increasing participation in service co-production processes enabled by new information technology and present the concept of customer efficiency to characterize a customer's role as a co-producer. The concept of customer efficiency as defined in Xue and Harker (2002) is used herein. Though the significance of customers' participation is conceptually discussed and highlighted in these previous papers, no analytical model has been developed to study how the level of customers' participation or involvement, which is a key parameter for the design of a service delivery process, and customer efficiency, a key measure of a customer's performance, influence a service firm's infrastructure, service quality, and demand function, and, consequently, the competition among service firms requiring different levels of self-service in their delivery processes.

There are several previous studies in which customers' influence is explicitly considered in a queuing model. Ha (1998) presents a GI/GI/1 queuing model with customer-chosen service rates and linear delay costs to solve the pricing problem of a single service facility where the facility and the customers jointly produce services. It is shown that due to congestion externalities, the service rate chosen by customers are always suboptimal for the facility and an optimal incentive-pricing scheme is developed to achieve optimal arrival rates and induce customers to choose optimal service rates. While in Ha (1998) the competition among service providers is not considered, we are primarily concerned about how customers' participation may influence the outcome of such competition. One of the key factors that we are interested in is the varying level of self-service or the proportion of the workload outsourced to the customer along with customer efficiency, which is not modeled in Ha (1998). In our model, the service rate for employee-delivered service is determined by the firm, not by the choice of a customer; and the service rate for self-service is a function of customer efficiency (pre-specified constant). In addition, the proportion of the workload that is outsourced to the customer is determined by the firm, not by the choice of a customer. Hall and Porteus (2000) present a quality competition model for a queuing and inventory system with no economies of scale. Gans (2002) develops a customer choice model in response to random variation in quality to study the influence of service quality on customer loyalty and then develops a normative model of the quality competition in an oligopoly based on this choice model. In our model, economies of scale are considered, customers do not have previous experience or history to base their choices on, and their choices are based solely on the full prices associated with the service product, which includes the explicit fee and customers' opportunity cost of service time (including

both self-service time and employee service time), rather than any single part of the full price (e.g., service time which reflects service quality).

In addition to the above mentioned papers that have explicitly considered the impact of customer's inputs in a queuing model, there is an extensive body of research works focusing on capacity and pricing problems with queuing systems that is related to our work in a general sense. These papers consider delay in service as a cost for the customer that has a negative effect on customer utility, and investigate related capacity and pricing decisions of a service facility. Mendelson (1985), Mendelson and Whang (1990), Dewan and Medelson (1990), Stidham (1992), So and Song (1998), van Meigham (2000), Mandelbaum and Shimkin (2000) analyze the issues in the case of a single service provider (monopoly). Others use competitive analysis approach: Reitman (1991), Li (1992), Kalai, Kamien and Rubinovitch (1992), Li and Lee (1994), Loch (1994), Deneckere and Peck (1995), Gilbert and Weng (1997), Leder and Li (1997), Armony and Haviv (1998), Chayet and Hopp (1999), and Cachon and Harker (2002). Some of these models consider the firms competing against each other only in one aspect, either price or performance but not both, while some others do not consider economies of scale. Self-service is generally not explicitly considered in these models. There are also studies on customers' competition for faster service using queuing models: Naor (1969), Lippman and Stidham (1977), Bell and Stidham (1983), Kulkarni (1983), Mendelson (1985), and Afeche and Mendelson (2001). In our model we consider the competition of the firms rather than that of the customers.

Cachon and Harker (2002) investigate the impact of the presence of economies of scale on market competition between firms that provide similar service products and found that the existence of economies of scale provides a strong motivation for outsourcing. The model we apply herein is an extension of the queuing game model in Cachon and Harker (2002). While Cachon and Harker (2002) are primarily concerned about the effect of economies of scale on firms' outsourcing decisions in a competitive environment, we focus on the impact of the level of customers' participation and customer efficiency on service providers' competition. Cachon and Harker (2002) consider outsourcing to an outside supplier whose goal is to maximize its profit; we consider herein a special case of outsourcing, one in which the service task is delegated to the customer who wants to minimize her cost, including both the time opportunity cost to complete the service and the explicit purchase cost. While an outside supplier generally has no direct influence on the demand function a firm faces, customers has a more complicated influence on the competition through their dual roles as both co-producers and patrons with direct influence on both service quality (service time) and demand. Cachon and Harker (2002) consider either to keep the whole service operation in-house or to outsource it completely; we consider the more general case of service co-production wherein the firm can outsource any proportion of the whole service task to the customer, ranging from

zero to 100%. That is, the proportion of the workload outsourced to the customer can be any continuous value within the range between zero and one (including zero and one). One of our findings is consistent with the finding in Cachon and Harker (2002): economies of scale provide a strong motivation for outsourcing to customers.

Besides Cachon and Harker (2002), there is an extensive literature in outsourcing that relates to our work. In particular, our work is related to the body of operations management literature that considers the primary benefit of outsourcing as cost-reduction: McMillan (1990), Venkatesan (1992), and van Miegham (1999). In economics, transaction cost theory (Williamson 1979), incomplete contracts (Grossman and Hart 1986), and assets ownership (Baker, Gibbons and Murphy 2001) are used to explain the motivation for outsourcing. In marketing, migrating price competition is shown to be one major benefit for suppliers to outsource the retailing function (McGuire and Staelin 1983). Outsourcing to customers is generally not explicitly considered in the previous literature. As discussed before, outsourcing to customers is unique and significantly different from a third party usually considered in the outsourcing literature as customers play dual roles in the service operations processes and, consequently, have multiple influences on market competition.

3 Model

In our model, there are two firms (Firm i and Firm j) that compete with each other in a market consisting of one service product. The production and delivery of this service product is a co-production process in which customers can be required to contribute certain amount of labor. That is, in general, the process consists of two phases: first, a customer performs self-service using self-service technology supported by the firm; and second, a customer enters an M/M/1 queue at the firm's service counter to get personal service from the firm's employees. For each customer, the system is a two-server system where a customer serves himself/herself at the first server and the employee serves the customer at the second server. We also assume that the firm can choose to provide only self-service support with no employee counter service, or to provide full employee service with no self-service required or supported. In the first case, customers complete self-service at the self-service server and then exit the system; in the second case, customers go to the employee server directly without going through the self-service server. In particular, we make the following assumptions:

1. Any part of the workload can be accomplished either through customer self-service or with employee counter service. The level of self-service is represented by ρ_i , $0 \leq \rho_i \leq 1$. The change of workload allocation is accounted for by the change of the service rate. For example, cutting a firm employee's service workload in half is equivalent to doubling her service rate.

To simplify the the notation, we normalize the workload $w_i = 1$.

2. Customers arrive at the system with demand rate d_i .
3. The waiting time for self-service is zero, and the expected self-service service time is

$$s_i = \rho_i e_i \tag{1}$$

where e_i indicates the inverse of the expected customer's productivity (customer efficiency).

4. There is infinite waiting space at the employee server. Expected time a customer spends in the employee service sub-system (including waiting time in the queue and employee service time at the server) is

$$g_i = \frac{1}{\frac{\mu_i}{1-\rho_i} - d_i}, \tag{2}$$

where μ_i indicates the expected employee productivity (employee efficiency).

5. We assume that the customer group is homogeneous in terms of unit opportunity cost, which is normalized to one.

The system described above is similar to the so-called tandem or sequential queuing system.

3.1 Demand Function

The market demand function for each firm is a function of the full prices of both firms. For a customer, the full price includes the explicit purchase price, the opportunity cost of self-service time, and the opportunity cost of the time spent at Firm i to receive employee service, with customers' unit opportunity cost normalized to one, an assumption that we may relax in future research. Thus, the full price consists of three parts: the explicit fees, p_i , the implicit price of self-service (i.e., the time that a customer is expected to spend for self-service), s_i , and the firm's performance (the time that a customer is expected to spend at Firm i to receive the employee service), g_i . That is, for Firm i (analogously for Firm j), the demand function is:

$$d_i(f_i, f_j) = d_i(p_i + s_i + g_i, p_j + s_j + g_j) \tag{3}$$

Assume that customers only act upon the full price. That is, any combination of explicit fees, implicit cost for self-service, and firm performance that add up to the same full price level is viewed as the same from a customer's perspective. The two firms simultaneously decide on the full prices, including the explicit fee and the self-service level (consequently, customers' cost of self-service time

and employee service time). We also assume that for any given f_i and f_j , resulting in a fixed demand rate d_i , Firm i has a unique optimal distribution of the total workload, ρ_i , which results in a unique (s_i, g_i) , given workload, customer efficiency, and employee efficiency.

3.2 Cost Function

We assume that the firm incurs a direct capacity cost for counter support (i.e., $n_i\mu_i$) but does not incur a *direct capacity* cost for self-service. Instead, we consider an indirect cost of customer self-service in this model. The indirect cost of self service results from the fact that a customer may be less efficient for a given service task and, hence requires more time to complete ρ_i units of the work than the firm employee could. We acknowledge that in reality there is the cost for building and maintaining the necessary infrastructure for customer self-service (e.g., an Internet bank incurs the cost for building and maintaining its website and database as well as the cost for the back office operations that support customer self-service). However, self-service technology is, in general, a relatively low cost means to deliver service to the customers as it significantly reduces the amount of labor costs and eliminates the huge capital investment for having brick-and-mortar stores. When taking into account the usually large capacity associated with the self-service technology such as a website linked to a database, the average cost per self-service is much lower than the average cost per employee service. For example, on average a transaction completed by the customer through the Internet costs the bank \$0.17 while the same transaction completed by a bank employee at the bank's branch costs \$1.59 according to the data from a major U.S. retail bank. Given the magnitude of the difference, in order to keep the model analytically tractable, we assume that the direct unit capacity cost is almost negligible relative to the unit capacity cost for employee counter service. In fact, the model can be easily extended to include a direct cost for self-service support and many of the results herein will still hold.

Therefore, Firm i 's self-service support capacity cost is zero and its employee-based service capacity cost is $n_i \cdot \mu_i$ to operate with a service rate

$$\mu_i = (g_i^{-1} + d_i)(1 - \rho_i). \quad (4)$$

Firm i incurs higher capacity cost at a service counter when it lowers the service time or increases the work load. A firm's capacity cost for employee service is also influenced by the demand rate.

Thus, Firm i 's cost function is:

$$C_i = n_i\mu_i = n_i(g_i^{-1} + d_i)(1 - \rho_i), n_i > 0, \rho_i \in [0, 1] \quad (5)$$

3.3 Profit Function

We have the following profit function for Firm i:

$$\pi_i(f_i, g_i, \rho_i, f_j) = (f_i - \rho_i e_i - g_i)d_i - n_i(g_i^{-1} + d_i)(1 - \rho_i), \rho_i \in [0, 1] \quad (6)$$

With (f_i, ρ_i, f_j) fixed, we have:

$$\frac{\partial \pi_i}{\partial g_i} = -d_i + n_i(1 - \rho_i)g_i^{-2} \quad (7)$$

$$\frac{\partial^2 \pi_i}{\partial g_i^2} = -2n_i(1 - \rho_i)g_i^{-3} < 0 \quad (8)$$

Equation (8) shows that with (f_i, ρ_i, f_j) fixed, π_i is concave with respect to g_i . Also using the first order condition (FOC) for optimization, the optimal operational performance of employee service for firm i is:

$$g_i^* = \sqrt{\frac{n_i(1 - \rho_i)}{d_i}} \quad (9)$$

Thus, Firm i's profit function can be restated as:

$$\begin{aligned} \pi_i(f_i, \rho_i, f_j) &= (f_i - \rho_i e_i - \sqrt{\frac{n_i(1 - \rho_i)}{d_i}})d_i - n_i(\sqrt{\frac{d_i}{n_i(1 - \rho_i)}} + d_i)(1 - \rho_i) \\ &= [f_i - \rho_i e_i - n_i(1 - \rho_i)]d_i - 2\sqrt{n_i(1 - \rho_i)d_i} \end{aligned} \quad (10)$$

$$= [f_i - \rho_i(e_i - n_i) - n_i]d_i - 2\sqrt{n_i(1 - \rho_i)d_i} \quad (11)$$

It is natural to assume $e_i > n_i$; i.e., customers are less efficient per unit of processing time than the firm. Hence, the first term is decreasing in ρ_i : you can charge less if the customer does more self service. The second term is increasing in ρ_i : you push work to the customer and you don't have the server idle as much.

3.4 Economies of Scale

Firm i's profit function in (11) can also be written as

$$\pi_i(f_i, \rho_i, f_j) = (f_i - c_i)d_i - \phi_i d_i^{\gamma_i} \quad (12)$$

where $c_i = \rho_i(e_i - n_i) + n_i$, $\phi_i = 2\sqrt{n_i(1 - \rho_i)}$, $\gamma_i = 1/2$.

Equation (12) shows that economies of scale exist when the firm provides some employee counter

service with $\rho_i \neq 1$. If the firm requires complete self-service with $\rho_i = 1$, then constant returns to scale exists instead.

3.5 Optimal Setting of the Self-service Level

From a long-run perspective, ρ_i , the level of self-service of the service product or the distribution of the workload between the customer self-service server and the employee counter service server, is a variable that a firm can change rather than a pre-specified constant. At the optimal performance level of $g_i = g_i^* = \sqrt{\frac{n_i(1-\rho_i)}{d_i}}$, we have the firm's profit as a function of (f_i, ρ_i, f_j)

$$\pi_i(f_i, \rho_i, f_j) = [f_i - \rho_i(e_i - n_i) - n_i]d_i - 2\sqrt{n_i(1 - \rho_i)d_i} \quad (13)$$

With (f_i, f_j) fixed,

$$\frac{\partial \pi_i}{\partial \rho_i} = -(e_i - n_i)d_i + \sqrt{\frac{n_i d_i}{1 - \rho_i}} \quad (14)$$

$$\frac{\partial^2 \pi_i}{\partial \rho_i^2} = \frac{\sqrt{n_i d_i}}{2} (1 - \rho_i)^{-\frac{3}{2}} \geq 0, \rho_i \in [0, 1] \quad (15)$$

So $\pi_i(f_i, \rho_i, f_j)$ is convex over ρ_i . As a result, the optimal setting of ρ_i is either one or zero, depending on the value of the profit function:

$$\rho_i^* = \arg \max_{\rho_i} \pi_i(f_i, \rho_i, f_j), \rho_i \in \{0, 1\} \quad (16)$$

The fact that the profit function is convex over ρ_i says that the firm's profit can be minimized by attempting to implement an intermediate solution of some self service and some counter service. This result predicts that extreme solutions should prevail, either firms push for complete self service or they push for complete employee service. However, in practice many other factors such as customer convenience, cross-selling, and other managerial issues may force firms to provide a combined package of both types of services or to make both service channels available to the customer by choosing $0 < \rho_i < 1$. In reality, a service can hardly be pure self-service without any employee service required or pure employee service without any self-service involved. Thus, we expect that a firm's most profitable strategy in the long-run is to provide a largely self-service-only product by setting ρ_i close to one, or largely full-service product by setting ρ_i close to zero for certain levels of service demand.

4 A Two-Firm Queuing Game with Service Co-production

4.1 A Two-Firm Symmetric Sub-game

Now we discuss the optimal strategy for two competitive firms in a symmetric game ($w_i = w_j = 1, e_i = e_j = e, \mu_i = \mu_j = \mu, n_i = n_j = n$) with the linear demand function

$$d_i(f_i, f_j) = a - b(f_i - f_j), \quad a > 0, b > 0 \quad (17)$$

4.1.1 Self-service vs. Self-service

Assume that both firms require complete self-service with no employee counter service provided: $\rho_i = \rho_j = 1$.

We then have the following profit function for Firm i (the same for Firm j):

$$\begin{aligned} \pi_i(f_i, f_j) &= (f_i - e_i)d_i \\ &= (f_i - e_i)[a - b(f_i - f_j)] \\ &= -bf_i^2 + (a + be_i + bf_j)f_i - ae_i - be_if_j \end{aligned} \quad (18)$$

Then

$$\frac{\partial \pi_i}{\partial f_i} = -2bf_i + a + be_i + bf_j \quad (19)$$

Since in a symmetric game the optimal full prices of the two firms are equal, $f_i^* = f_j^*$, using the first-order conditions, we have

$$\frac{\partial \pi_i}{\partial f_i} \Big|_{f_i=f_i^*} = -bf_i^* + a + be_i = 0 \quad (20)$$

Thus

$$f_i^* = f_j^* = \frac{a}{b} + e_i \quad (21)$$

$$\pi_i^* = \pi_j^* = \frac{a^2}{b} \quad (22)$$

We also have:

$$g_i^* = 0 \quad (23)$$

$$s_i^* = e_i \quad (24)$$

$$p_i^* = \frac{a}{b} \quad (25)$$

4.1.2 Full-service vs. Full-service

Assume that both firms provide full-service only with no self-service required or supported: $\rho_i = \rho_j = 0$. We then have Firm i's profit function as below (the same for Firm j):

$$\begin{aligned}\pi_i(f_i, f_j) &= (f_i - n_i)d_i - 2\sqrt{n_i d_i} \\ &= (f_i - n_i)[a - b(f_i - f_j)] - 2\sqrt{n_i[a - b(f_i - f_j)]} \\ &= -bf_i^2 + [a + b(n_i + f_j)]f_i - 2\sqrt{n_i[a - b(f_i - f_j)]} - an_i + bn_i f_j\end{aligned}\quad (26)$$

Thus

$$\frac{\partial \pi_i}{\partial f_i} = a - 2bf_i + bf_j + bn_i + b\sqrt{\frac{n_i}{a - b(f_i - f_j)}}\quad (27)$$

As $f_i^* = f_j^*$ in a symmetric game, we have

$$\frac{\partial \pi_i}{\partial f_i} \Big|_{f_i=f_i^*} = a - bf_i^* + bn_i + b\sqrt{\frac{n_i}{a}} = 0\quad (28)$$

Thus

$$f_i^* = f_j^* = \frac{a}{b} + n_i + \sqrt{\frac{n_i}{a}}\quad (29)$$

$$\pi_i^* = \pi_j^* = \frac{a^2}{b} - \sqrt{n_i a}\quad (30)$$

We also have

$$g_i^* = \sqrt{\frac{n_i}{a}}\quad (31)$$

$$s_i^* = 0\quad (32)$$

$$p_i^* = \frac{a}{b} + n_i\quad (33)$$

4.1.3 Both: Combination of Self-service and Full-service

Assume that both firms provide a combination of self-service and employee service with the same level of self-service required: $0 < \rho_i = \rho_j < 1$. We then have the following profit function for Firm i (the same for Firm j)

$$\pi_i(f_i, f_j) = [f_i - \rho_i(e_i - n_i) - n_i]d_i - 2\sqrt{n_i(1 - \rho_i)d_i}\quad (34)$$

Accordingly

$$\frac{\partial \pi_i}{\partial f_i} = -2bf_i + bf_j + a + b\rho_i e_i + bn_i(1 - \rho_i) + b\sqrt{\frac{n_i(1 - \rho_i)}{a - b(f_i - f_j)}} \quad (35)$$

As $f_i^* = f_j^*$ in a symmetric game, we have

$$\frac{\partial \pi_i}{\partial f_i} \Big|_{f_i=f_i^*} = -bf_i^* + a + b\rho_i e_i + bn_i(1 - \rho_i) + b\sqrt{\frac{n_i(1 - \rho_i)}{a}} = 0 \quad (36)$$

Thus

$$f_i^* = f_j^* = \frac{a}{b} + \rho_i e_i + n_i(1 - \rho_i) + \sqrt{\frac{n_i(1 - \rho_i)}{a}} \quad (37)$$

$$\pi_i^* = \pi_j^* = \frac{a^2}{b} - \sqrt{n_i(1 - \rho_i)a} \quad (38)$$

We also have

$$g_i^* = g_j^* = \sqrt{\frac{n_i(1 - \rho_i)}{a}} \quad (39)$$

$$s_i^* = s_j^* = \rho_i e_i \quad (40)$$

$$p_i^* = p_j^* = \frac{a}{b} + n_i(1 - \rho_i) \quad (41)$$

4.1.4 Summary of Symmetric Sub-game

Table 1 summarizes the characteristics of the three sub-games:

Table 1 Results of Symmetric Sub-games

	$\rho_i = \rho_j = 1$	$\rho_i = \rho_j = 0$	$0 < \rho_i = \rho_j < 1$
g_i^*	0	$\sqrt{\frac{n_i}{a}}$	$\sqrt{\frac{n_i(1-\rho_i)}{a}}$
s_i^*	e_i	0	$\rho_i e_i$
p_i^*	$\frac{a}{b}$	$\frac{a}{b} + n_i$	$\frac{a}{b} + n_i(1 - \rho_i)$
f_i^*	$\frac{a}{b} + e_i$	$\frac{a}{b} + n_i + \sqrt{\frac{n_i}{a}}$	$\frac{a}{b} + \rho_i e_i + n_i(1 - \rho_i) + \sqrt{\frac{n_i(1-\rho_i)}{a}}$
d_i^*	a	a	a
π_i^*	$\frac{a^2}{b}$	$\frac{a^2}{b} - \sqrt{n_i a}$	$\frac{a^2}{b} - \sqrt{n_i a(1 - \rho_i)}$

Table 2 Comparison of the Equilibria of the Symmetric Sub-games

Comparison	
g_i^*	$g_i^*(\rho_i = \rho_j = 1) < g_i^*(0 < \rho_i = \rho_j < 1) < g_i^*(\rho_i = \rho_j = 0)$
s_i^*	$s_i^*(\rho_i = \rho_j = 0) < s_i^*(0 < \rho_i = \rho_j < 1) < s_i^*(\rho_i = \rho_j = 1)$
p_i^*	$p_i^*(\rho_i = \rho_j = 1) < p_i^*(0 < \rho_i = \rho_j < 1) < p_i^*(\rho_i = \rho_j = 0)$
f_i^*	(See Theorem 1)
d_i^*	$d_i^*(\rho_i = \rho_j = 1) = d_i^*(0 < \rho_i = \rho_j < 1) = d_i^*(\rho_i = \rho_j = 0)$
π_i^*	$\pi_i^*(\rho_i = \rho_j = 0) < \pi_i^*(0 < \rho_i = \rho_j < 1) < \pi_i^*(\rho_i = \rho_j = 1)$

Theorem 1 Consider a symmetric game for Firm i and Firm j in which $w_i = w_j = 1, e_i = e_j = e, \mu_i = \mu_j = \mu, n_i = n_j = n$ with linear demand functions $d_i = a - b(f_i - f_j)$, and $d_j = a - b(f_j - f_i)$. Define

$$f_i^*(\rho_i = \rho_j = 1) = \arg \max_{f_i} \pi_i(f_i, \rho_i = \rho_j = 1, f_j) \quad (42)$$

$$f_i^*(\rho_i = \rho_j = 0) = \arg \max_{f_i} \pi_i(f_i, \rho_i = \rho_j = 0, f_j) \quad (43)$$

$$f_i^*(0 < \rho_i = \rho_j < 1) = \arg \max_{f_i} \pi_i(f_i, 0 < \rho_i = \rho_j < 1, f_j). \quad (44)$$

Also define

$$h_1 = n_i + \sqrt{\frac{n_i}{a} \frac{1 - \sqrt{1 - \rho_i}}{\rho_i}}, \rho_i \in (0, 1) \quad (45)$$

$$h_2 = n_i + \sqrt{\frac{n_i}{a}}, \quad (46)$$

$$h_3 = n_i + \sqrt{\frac{n_i}{a(1 - \rho_i)}}, \rho_i \in (0, 1), \quad (47)$$

where it is easy to show that $h_1 < h_2 < h_3$. Then

1. If $e_i < h_1$, then $f_i^*(\rho_i = \rho_j = 1) < f_i^*(0 < \rho_i = \rho_j < 1) < f_i^*(\rho_i = \rho_j = 0)$.
2. If $h_1 < e_i < h_2$, then $f_i^*(\rho_i = \rho_j = 1) < f_i^*(\rho_i = \rho_j = 0) < f_i^*(0 < \rho_i = \rho_j < 1)$.
3. If $h_2 < e_i < h_3$, then $f_i^*(\rho_i = \rho_j = 0) < f_i^*(\rho_i = \rho_j = 1) < f_i^*(0 < \rho_i = \rho_j < 1)$.
4. If $e_i > h_3$, then $f_i^*(\rho_i = \rho_j = 0) < f_i^*(0 < \rho_i = \rho_j < 1) < f_i^*(\rho_i = \rho_j = 1)$.

(The proofs of Theorem 1 is straightforward and thus is omitted herein).

According to Table 1-2 and Theorem 1, in a symmetric game:

1. The average counter service time is the longest in the (full-service, full-service) equilibrium and the shortest (zero) in the (self-service, self-service) equilibrium. The converse is true in the case of self-service time.
2. The explicit price for the service product is the lowest in the (self-service, self-service) equilibrium while the explicit price in the (full-service, full-service) equilibrium is the highest.
3. If customers are highly efficient, the full price in the (self-service, self-service) equilibrium is the lowest while the full price in the (full-service, full-service) equilibrium is the highest. However, if customers are highly inefficient, then the opposite is true. Interestingly, when customers are neither super efficient nor super inefficient, the equilibrium in which customers are required to complete part of the service task actually has the highest full price.
4. The most profitable equilibrium is the (self-service, self-service) equilibrium for the two firms, while the least profitable equilibrium is the (full-service, full-service) equilibrium. This result is consistent with Cachon and Harker (2002): both firms are better off when they both outsource the work.

4.2 Two Firm Asymmetric Sub-game: Self-service vs. Full-service

Now we assume that Firm i requires complete self-service with no employee service provided, and Firm j provides full-service with no self-service required or supported. In addition, we retain the assumption that the two firms are identical in other aspects: $w_i = w_j = 1, e_i = e_j = e, \mu_i = \mu_j = \mu, n_i = n_j = n$. Thus, the subgame is symmetric except that $\rho_i = 1$ and $\rho_j = 0$. We also retain the linear demand function assumption for Firm i and Firm j: $d_i = a - b(f_i - f_j)$ and

$d_j = a - b(f_j - f_i)$. Obviously $d_i + d_j = 2a$. The profit functions can be restated as

$$\begin{aligned}\pi_i(f_i, \rho_i = 1, f_j) &= (f_i - e_i)d_i(f_i, f_j) \\ \pi_j(f_j, \rho_j = 0, f_i) &= (f_j - n_j)d_j(f_j, f_i) - 2\sqrt{n_j d_j(f_j, f_i)}\end{aligned}$$

Thus,

$$\frac{\partial \pi_i}{\partial f_i} = d_i(f_i, f_j) - b(f_i - e_i) \quad (48)$$

$$\begin{aligned}\frac{\partial \pi_j}{\partial f_j} &= d_j(f_j, f_i) - b(f_j - n_j - \sqrt{\frac{n_j}{d_j(f_j, f_i)}}) \\ &= (2a - d_i(f_j, f_i)) - b(f_j - n_j - \sqrt{\frac{n_j}{2a - d_i(f_j, f_i)}})\end{aligned} \quad (49)$$

Using the FOC, we have:

$$f_i^* = \frac{d_i^*}{b} + e_i \quad (50)$$

$$f_j^* = \left(\frac{2a}{b} + n_j\right) - \frac{d_i^*}{b} + \sqrt{\frac{n_j}{2a - d_i^*}} \quad (51)$$

Also, using the demand functions, we have

$$\pi_i(f_i, f_j) = (f_i - e_i) [a - b(f_i - f_j)] \quad (52)$$

Using the FOC, we have

$$\frac{\partial \pi_i}{\partial f_i} \Big|_{(f_i^*, f_j^*)} = -2bf_i^* + (a + bf_j^* + be_i) = 0 \quad (53)$$

That is,

$$f_j^* = 2f_i^* + \left(e_i - \frac{a}{b}\right) \quad (54)$$

Using (50), (51), and (54) to solve for d_i^* , we have

$$\frac{3d_i^*}{b} - \sqrt{\frac{n_j}{2a - d_i^*}} + \left(e_i - \frac{3a}{b} - n_j\right) = 0 \quad (55)$$

As $n_j > 0$, the above equation is equal to

$$\frac{3d_i^*}{n_j b} - \frac{1}{\sqrt{n_j(2a - d_i^*)}} + \frac{1}{n_j} \left(e_i - \frac{3a}{b}\right) = 1 \quad (56)$$

Now we define

$$r = \frac{d_i^*}{b}, \quad (57)$$

where $r < \frac{2a}{b}$ as $d_i^* < 2a$ (If $d_i^* = 2a$, then $d_j^* = 0$, which means that Firm j exits the market, which is not an equilibrium situation). We then define

$$h(r) = \frac{3}{n_j}r - \frac{1}{\sqrt{n_j(2a - br)}} + \frac{1}{n_j}\left(e_i - \frac{3a}{b}\right) \quad (58)$$

As

$$\frac{\partial^2 h}{\partial r^2} = -\frac{3b^2}{4} \frac{1}{\sqrt{n_j}} (2a - br)^{-5/2} < 0, \quad (59)$$

$h(r)$ is concave over r .

Define

$$\vec{r} = \arg \max_r \{h(r) | h(r) = \frac{3}{n_j}r - \frac{1}{\sqrt{n_j(2a - br)}} + \frac{1}{n_j}\left(e_i - \frac{3a}{b}\right), r < \frac{2a}{b}\} \quad (60)$$

Using the FOC, we have

$$\vec{r} = \frac{2a}{b} - 6^{-2/3} b^{-1/3} n^{1/3} \quad (61)$$

$$h(\vec{r}) = \frac{1}{n} \left(\frac{3a}{b} + e_i \right) - (3 \cdot 6^{-2/3} + 6^{1/3}) b^{-1/3} n^{-2/3} \quad (62)$$

If $h(\vec{r}) > 1$, there exist two solutions to $h(r) = 1$ that could be local maximum of $\pi(r)$. A solution can be an equilibrium only if both firms make positive profits at that point. Note that

$$\pi_i^*(r) = br^2 \quad (63)$$

$$\pi_j^*(r) = b\left(r - \frac{2a}{b}\right)^2 - \sqrt{n_j(2a - br)} \quad (64)$$

Now we define

$$r_1 = 0 \quad (65)$$

$$r_2 = \frac{2a}{b} - b^{-1/3} n_j^{1/3}. \quad (66)$$

It can be shown that $\pi_i^*(r) > 0, \pi_j^*(r) > 0$ if and only if $r_1 < r < r_2$. Note that $r_2 < \vec{r}$. So the smaller solution to $h(r) = 1$, $r^* = \min\{r | h(r) = 1\}$, is the unique equilibrium if $r_1 < r^* < r_2$. Note that if $a > \frac{1}{2} b^{2/3} n_j^{1/3}$, then $r_1 < r_2$.

Now we show that there exists such an r^* . Note that

$$\frac{\partial h(r)}{\partial r} = \frac{3}{n_j} - \frac{b}{2} \frac{1}{\sqrt{n_j}} (2a - br)^{-3/2} > 0. \quad (67)$$

Since $h(r)$ is concave over r , $h(r)$ strictly increases as r increases when $r < \bar{r}$. So if $h(r_1) < 1, h(r_2) > 1$, then there must exist an $r^* \in (r_1, r_2)$ such that $h(r^*) = 1$; and r^* is the unique equilibrium (note that as $h(r_2) < h(\bar{r})$, if $h(r_2) > 1$ holds, $h(\bar{r}) > 1$ holds automatically).

Note that

$$h(r_1) = \frac{1}{n_j} \left(e_i - \frac{3a}{b} \right) - \frac{1}{\sqrt{2n_j a}} < 1 \quad (68)$$

is equal to

$$e_i < \left(n_j + \frac{3a}{b} \right) + \sqrt{\frac{n_j}{2a}} \quad (69)$$

Also

$$h(r_2) = \frac{1}{n_j} \left(\frac{3a}{b} + e_i \right) - 4b^{-1/3} n_j^{-2/3} > 1 \quad (70)$$

is equal to

$$e_i > \left(n_j - \frac{3a}{b} \right) + 4b^{-1/3} n_j^{1/3} \quad (71)$$

It can be shown that under the assumption $a > \frac{1}{2} b^{2/3} n_j^{1/3}$, $\left(n_j - \frac{3a}{b} \right) + 4b^{-1/3} n_j^{1/3} < \left(n_j + \frac{3a}{b} \right) + \sqrt{\frac{n_j}{2a}}$ holds. Thus, the conditions $h(r_1) < 1$ and $h(r_2) > 1$ requires

$$\left(n_j - \frac{3a}{b} \right) + 4b^{-1/3} n_j^{1/3} < e_i < \left(n_j + \frac{3a}{b} \right) + \sqrt{\frac{n_j}{2a}} \quad (72)$$

Thus, the following theorem shows that under certain conditions, there exists a unique equilibrium in the market where both firms to have positive profits when one firm requires complete self-service with no employee counter service provided and the other provides full-service with no self-service required or supported.

Theorem 2 (*Existence of Equilibrium in the Asymmetric Sub-game: Self-service vs. Full-service*)

Assume that Firm i requires complete self-service with no employee counter service provided and Firm j provides full-service with no self-service required or supported; i.e., $\rho_i = 1, \rho_j = 0$. Also assume that $w_i = w_j = 1, e_i = e_j = e, \mu_i = \mu_j = \mu, n_i = n_j = n$, as well as linear demand functions $d_i = a - b(f_i - f_j)$, and $d_j = a - b(f_j - f_i)$.

Define

$$r = \frac{d_i}{b}, (r < \frac{2a}{b}) \quad (73)$$

$$r_1 = 0 \quad (74)$$

$$r_2 = \frac{2a}{b} - b^{-1/3}n_j^{1/3}. \quad (75)$$

$$r^* = \min\{r|h(r) = \frac{3}{n_j}r - \frac{1}{\sqrt{n_j(2a-br)}} + \frac{1}{n_j}(e_i - \frac{3a}{b}) = 1\} \quad (76)$$

Assume

$$a > \frac{1}{2}b^{2/3}n_j^{1/3}. \quad (77)$$

If

$$(n_j - \frac{3a}{b}) + 4b^{-1/3}n_j^{1/3} < e_i < (n_j + \frac{3a}{b}) + \sqrt{\frac{n_j}{2a}} \quad (78)$$

then there exists r^* , $r^* \in (r_1, r_2)$, such that $(\rho_i^* = 1, \rho_j^* = 0)$ is the unique equilibrium of the game for Firm i and Firm j . In such an equilibrium, Firm i has a positive profit $\pi_i^* = b \cdot r^{*2}$ with demand $d_i^* = br^*$ while Firm j has a positive profit $\pi_j^* = b(r^* - \frac{2a}{b})^2 - \sqrt{n_j(2a-br^*)}$ with a demand $d_j^* = 2a - br^*$.

Theorem 2 states that the (self-service, full-service) equilibrium exists only when customer efficiency is within certain range. That is, if customers are highly efficient or highly inefficient, the two type of service firms may not both exist in market equilibrium. On the other hand, if customers are not highly efficient or highly inefficient, it is possible for full-service firms and self-service-only firms to coexist in a market equilibrium, a scenario we observe in many service industries.

4.3 A Two Firm Game: Self-service vs. Full-service

As shown in Section 3.5, the optimal setting of ρ for a firm is either zero or one in the long-run. Therefore, in this section, we discuss a game with two firms in which each firm sets their ρ equal to either zero or one with the assumption that they are identical in other aspects: $w_i = w_j = 1, e_i = e_j = e, \mu_i = \mu_j = \mu, n_i = n_j = n$. We also continue to assume that demand is a linear function for both Firm i and Firm j : $d_i = a - b(f_i - f_j)$, and $d_j = a - b(f_j - f_i)$. Obviously $d_i + d_j = 2a$. Define

$$\bar{f}_i = f_i^*(\rho_i = 1, \rho_j = 0) \quad (79)$$

$$\tilde{f}_i = f_i^*(\rho_i = 0, \rho_j = 1). \quad (80)$$

Consequently, we have

$$\bar{p}_i = p_i^*(\rho_i = 1, \rho_j = 0) \quad (81)$$

$$\tilde{p}_i = p_i^*(\rho_i = 0, \rho_j = 1). \quad (82)$$

Also define:

$$\bar{d}_i = d_i^*(\rho_i = 1, \rho_j = 0) \quad (83)$$

$$\tilde{d}_i = d_i^*(\rho_i = 0, \rho_j = 1) \quad (84)$$

All the notations for Firm j are analogous. Since Firm i and Firm j are identical except $\rho_i \neq \rho_j$, we denote:

$$\bar{f}_i = \bar{f}_j = \bar{f}, \quad \tilde{f}_i = \tilde{f}_j = \tilde{f} \quad (85)$$

$$\bar{p}_i = \bar{p}_j = \bar{p}, \quad \tilde{p}_i = \tilde{p}_j = \tilde{p} \quad (86)$$

$$\bar{d}_i = \bar{d}_j = \bar{d}, \quad \tilde{d}_i = \tilde{d}_j = \tilde{d} \quad (87)$$

In this section, we focus on characterizing the conditions for the existence of the three possible equilibria: (self service, self-service), (full-service, full-service), and (self-service, full-service). We show that the existence conditions can essentially be expressed as the limits of the explicit price of the self-service-only product in a (self-service, full-service) equilibrium, \bar{p}_i .

Table 3 states the two firms' payoffs when they choose different settings of ρ to compete with each other.

Table 3 A Game with Service Coproduction: Self-service vs. Full-service

		Firm j	
		<i>Self</i>	<i>Full</i>
Firm i	<i>Self</i>	$(\frac{a^2}{b}, \frac{a^2}{b})$	$(\frac{\bar{d}^2}{b}, \frac{\tilde{d}^2}{b} - \sqrt{n\tilde{d}})$
	<i>Full</i>	$(\frac{\tilde{d}^2}{b} - \sqrt{n\tilde{d}}, \frac{\bar{d}^2}{b})$	$(\frac{a^2}{b} - \sqrt{na}, \frac{a^2}{b} - \sqrt{na})$

Now we consider the row player, Firm i's strategy and payoffs. First we denote

$$x_1 = \frac{a^2}{b} \quad (88)$$

$$x_2 = \frac{\tilde{d}^2}{b} - \sqrt{n\tilde{d}} \quad (89)$$

$$x_3 = \frac{\bar{d}^2}{b} \quad (90)$$

$$x_4 = \frac{a^2}{b} - \sqrt{na} \quad (91)$$

Next we consider the conditions for the existence of the three types of equilibria: (self-service, self-service), (full-service, full-service), and (self-service, full-service) individually.

4.3.1 Existence of a (Self-service, Self-service) Equilibrium

Obviously, $x_1 > x_4$ always holds as $n > 0, a > 0$. If $x_1 > x_2, x_3 > x_4$, Firm i's optimal strategy is to set $\rho_i = 1$ no matter whether Firm j sets its $\rho_j = 0$ or $\rho_j = 1$. The same holds for Firm j. Therefore, when $x_1 > x_2, x_3 > x_4$, the unique equilibrium of the game will be $(\rho_i^* = 1, \rho_j^* = 1)$. That is, the optimal response for each firm will be to set the self-service level at one; i.e., to require complete self-service.

Now we show such an equilibrium exists under certain conditions. Note that if $\tilde{d} \leq a$, then $x_1 > x_2$ holds. Similarly, if $\bar{d} \geq a$, then $x_3 > x_4$ holds.

Since $\tilde{d} + \bar{d} = 2a$ and $\bar{f} = \frac{\bar{d}}{b} + e$, these conditions are equal to

$$\bar{f} \geq \frac{a}{b} + e \quad (92)$$

As $\bar{f} = \bar{p} + \bar{g} + \bar{s}$ where $\bar{g} = 0$ and $\bar{s} = e$. So the above condition is equal to

$$\bar{p} \geq \frac{a}{b} \quad (93)$$

Based on the analysis above, we have the following theorem:

Theorem 3 (*Existence of a (Self-service, Self-service) Equilibrium*)

Consider a two-firm game in which $w_i = w_j = 1, e_i = e_j = e, \mu_i = \mu_j = \mu, n_i = n_j = n$. Define

$$\bar{p}_i = p_i^*(\rho_i = 1, \rho_j = 0). \quad (94)$$

If

$$\bar{p}_i \geq \frac{a}{b} \quad (95)$$

then there exist a unique equilibrium $(\rho_i^* = 1, \rho_j^* = 1)$ in which both firms require complete self-service with $f_i^* = f_j^* = \frac{a}{b} + e$, $p_i^* = p_j^* = \frac{a}{b}$, $d_i^* = d_j^* = a$ and $\pi_i^* = \pi_j^* = \frac{a^2}{b}$.

According to Theorem 3, for a (self-service, self-service) equilibrium to exist, a lower bound on the optimal explicit price that the firm offering self-service-only product charges in a (self-service, full-service) competition scenario should not be violated. The fact that it is a lower bound on the explicit price suggests that to make (self-service, self-service) a profitable equilibrium for both firms, the explicit price for self-service-only product must be sufficiently high. Customers often demand a relatively lower explicit price as compensation for their self-service due to their extra labor hours, the delay of the service completion, and possibly lower quality due to their lack of professional skills. As a result, a self-service-only product can usually charge a lower price than the price for similar service product that is delivered with full-service. For example, the fee a customer is willing to pay for trading stock by herself through an Internet trading company's website is much lower than the fee a customer is willing to pay for having a broker trade the stocks for her. This condition suggests that if the market price for a self-service only product is too low, then (self-service, self-service) cannot be market equilibrium because the profit margin is too thin.

More importantly, though the higher profitability associated with the (self-service, self-service) equilibrium comes from the cost-savings generated by substituting the more expensive employee service with less expensive self-service, this theorem suggests that the existence of such a profitable (self-service, self-service) equilibrium critically depends on the prevention of downstream price competition (i.e., cutting the price low to increase the demand and lower average cost in the presence of economies of scale). As we discussed above, economies of scale are present in the queuing game unless both firms are self-service only. So when both firms outsource the service work to the customer completely, each firm now faces constant returns to scale instead of economies of scale, and the incentive to cut price in order to increase demand and lower average cost disappears. This result shows that both firms become better off by outsourcing to the customers because it not only lowers the firms' costs but also eliminates the incentives for downstream price competition, which is critical for the existence of the (self-service, self-service) equilibrium.

4.3.2 Existence of a (Full-service, Full-service) Equilibrium

If $x_2 > x_1, x_4 > x_3$, a firm is always better off by providing full-service than requiring complete self-service, regardless of the other firm's choice of its self-service level. Then (full-service, full-service) with $(\rho_i^* = 0, \rho_j^* = 0)$ is the equilibrium in which both firms provide full-service with no self-service

required or supported.

That is,

$$\frac{\tilde{d}^2}{b} - \sqrt{n\tilde{d}} > \frac{a^2}{b} \quad (96)$$

$$\frac{a^2}{b} - \sqrt{na} > \frac{\tilde{d}^2}{b} \quad (97)$$

Assume

$$a > b^{2/3}n^{1/3}, \quad (98)$$

which implies that $\frac{a^2}{b} - \sqrt{na} > 0$. Then the condition for $x_4 > x_3$ is equal to

$$\bar{d} < \sqrt{a^2 - b\sqrt{na}}. \quad (99)$$

Define

$$d_1 = \sqrt{a^2 - b\sqrt{na}}, \quad (100)$$

Then the condition for $x_4 > x_3$ is

$$\bar{d} < d_1 \quad (101)$$

Define

$$\pi(\tilde{d}) = \frac{\tilde{d}^2}{b} - \sqrt{n\tilde{d}} \quad (102)$$

Then

$$\frac{\partial \pi}{\partial \tilde{d}} = \frac{2\tilde{d}}{b} - \frac{1}{2}\sqrt{\frac{n}{\tilde{d}}} \quad (103)$$

$$\frac{\partial^2 \pi}{\partial \tilde{d}^2} = \frac{2}{b} + \frac{1}{4}\sqrt{n}\tilde{d}^{-3/2} > 0 \quad (104)$$

So $\pi(\tilde{d})$ is convex over \tilde{d} and $d_{\min} = \arg \min_{\tilde{d}} \pi(\tilde{d}) = 2^{-1/3}b^{2/3}n^{1/3}$, and $\min \pi(\tilde{d}) = \pi(d_{\min}) = (2^{-1/3} - 2^{-1/6})b^{1/3}n^{2/3} < 0$. Also, we have $\pi(\tilde{d} = 0) = 0$.

Define

$$d_2 = \left\{ \tilde{d} \mid \pi(\tilde{d}) = \frac{a^2}{b}, d_2 \in [0, 2a] \right\}, \quad (105)$$

then $d_2 > d_{\min}$. So $x_2 > x_1$ if and only if

$$\tilde{d} > d_2 \quad (106)$$

As $\tilde{d} + \bar{d} = 2a$, this condition is equal to

$$2a - \bar{d} > d_2, \quad (107)$$

which equals

$$\bar{d} < 2a - d_2 \quad (108)$$

Thus, the condition for $x_2 > x_1$, and $x_4 > x_3$ to hold is

$$0 < \bar{d} < \min \{2a - d_2, d_1\}, \text{ and } a > b^{2/3}n^{1/3} \quad (109)$$

Note that $a > b^{2/3}n^{1/3}$ also implies that $d_2 < 2a$, which holds as long as $a > \left(\frac{2}{9}\right)^{1/3} b^{2/3}n^{1/3} = 0.22b^{2/3}n^{1/3}$. As $\bar{f} = \frac{\bar{d}}{b} + e$, this condition equals

$$\bar{f} < \frac{\min \{2a - d_2, d_1\}}{b} + e \quad (110)$$

As $\bar{f} = \bar{p} + \bar{g} + \bar{s}$ where $\bar{g} = 0$ and $\bar{s} = e$. Thus, the condition is equal to

$$\bar{p} < \frac{\min \{2a - d_2, d_1\}}{b} \quad (111)$$

We then have the following theorem to characterize the condition for the existence of the (full-service, full-service) equilibrium.

Theorem 4 (*Existence of a (Full-service, Full-service) Equilibrium*)

Assume $a > b^{2/3}n^{1/3}$. Define

$$\bar{p}_i = p_i^*(\rho_i = 1, \rho_j = 0) \quad (112)$$

$$d_1 = \sqrt{a^2 - b\sqrt{na}} \quad (113)$$

$$d_2 = \left\{ \tilde{d} \mid \pi(\tilde{d}) = \frac{a^2}{b}, d_2 \in [0, 2a] \right\}. \quad (114)$$

If

$$\bar{p}_i < \frac{\min \{2a - d_2, d_1\}}{b} \quad (115)$$

then there exists the unique equilibrium of $(\rho_i^* = 0, \rho_j^* = 0)$, in which both firms provide full-service with no self-service required or supported, while $f_i^* = f_j^* = \frac{a}{b} + n + \sqrt{\frac{n}{a}}$, $p_i^* = p_j^* = \frac{a}{b} + n$, $d_i^* = d_j^* = a$, and $\pi_i^* = \pi_j^* = \frac{a^2}{b} - \sqrt{na}$.

Note that according to Theorem 4, the condition for the existence of the (full-service, full-service) equilibrium is represented by an upper bound on the explicit price for the self-service-only product in a (self-service, full-service) competitive scenario. This suggests that the full-service firms dominate the market if self-service-only firms fail to have enough demand at a high enough price to be profitable. We know that consumers are often unwilling to pay a high price for self-service-only products as they demand some compensation for their self-service. As a result, self-service-only firms usually have difficulty in raising their price without turning consumers away. As a result, they often have to position themselves at the low cost end of the market. But if the price is too low to generate a positive profit margin, the self-service-only firms may have to exit the market. This may partially explain why many business models which aimed at providing largely self-service-only type service product through the Internet did not succeed in gaining enough market share or securing enough market demand at a profitable price and eventually failed.

4.3.3 Existence of a (Self-service, Full-service) Equilibrium

In this section, we discuss the condition for one firm's optimal strategy to be the opposite of the other firm's choice between offering full-service product and offering self-service-only product. The underlying assumption is that the other firm's choice is known information by the time the decision needs to be made. Thus, we relax the assumption that two firms make the decisions simultaneously, in which case a (self-service, full-service) equilibrium may not exist. The assumption may hold in a long-run multi-stage competition rather than the one-stage competition we have discussed so far. Nevertheless, the existence condition for (self-service, full-service) equilibrium is $x_2 > x_1$, and $x_4 < x_3$.

From the above analysis, we know that the condition for $x_2 > x_1$ is

$$\bar{d} < 2a - d_2, \quad a > \left(\frac{2}{9}\right)^{1/3} b^{2/3} n^{1/3} \quad (116)$$

The condition for $x_4 < x_3$ is

$$d_1 < \bar{d} < 2a, \quad a > b^{2/3} n^{1/3}; \quad (117)$$

or

$$0 < \bar{d} < 2a, \quad a \leq b^{2/3} n^{1/3}. \quad (118)$$

So the condition for $x_2 > x_1, x_4 < x_3$ is

$$d_1 < \bar{d} < 2a - d_2, \quad a > b^{2/3} n^{1/3}; \quad (119)$$

or

$$0 < \bar{d} < 2a - d_2, \left(\frac{2}{9}\right)^{1/3} b^{2/3} n^{1/3} < a \leq b^{2/3} n^{1/3}. \quad (120)$$

Similarly, we have the conditions for $x_2 > x_1, x_4 < x_3$ as

$$\frac{d_1}{b} < \bar{p} < \frac{2a - d_2}{b}, \quad a > b^{2/3} n^{1/3}; \quad (121)$$

or

$$0 < \bar{p} < \frac{2a - d_2}{b}, \left(\frac{2}{9}\right)^{1/3} b^{2/3} n^{1/3} < a \leq b^{2/3} n^{1/3}. \quad (122)$$

Thus, we have the following theorem that characterizes the conditions for the existence of a (self-service, full-service) equilibrium:

Theorem 5 (*Existence of a (Self-service, Full-service) Equilibrium*)

Define

$$\bar{p}_i = p_i^*(\rho_i = 1, \rho_j = 0) \quad (123)$$

$$d_1 = \sqrt{a^2 - b\sqrt{na}} \quad (124)$$

$$d_2 = \left\{ \tilde{d} \mid \pi(\tilde{d}) = \frac{a^2}{b}, d_2 \in [0, 2a] \right\}. \quad (125)$$

If

$$\frac{d_1}{b} < \bar{p}_i < \frac{2a - d_2}{b}, \quad a > b^{2/3} n^{1/3}; \quad (126)$$

or

$$0 < \bar{p}_i < \frac{2a - d_2}{b}, \left(\frac{2}{9}\right)^{1/3} b^{2/3} n^{1/3} < a \leq b^{2/3} n^{1/3}. \quad (127)$$

then the equilibrium of the two-firm game is either $(\rho_i^* = 1, \rho_j^* = 0)$ or $(\rho_i^* = 0, \rho_j^* = 1)$ in which one firm requires complete self-service with no employee service committed while the other firm provides full-service with no self-service required or supported.

Here the condition for the existence of a (self-service, full-service) equilibrium is essentially a range of the explicit price for the self-service-only product with both lower and upper limits. It suggests that both the self-service-only product providers and the full-service product providers can coexist in a market equilibrium when the market price for the self-service only product is not too low or too high. In other words, the two types of service firms can coexist in a market equilibrium when the self-service-only product is not either cheap enough to drive the full-service firms out of the market or too high to gain excessive market share. Though many other factors are likely

involved, the price factor as stated in Theorem 5 has clearly played a role in the coexistence of both types of service providers in many service industries.

4.3.4 Summary

In summary, in a two-firm one stage game, both (self-service, self-service) and (full-service, full-service) can be market equilibria, but the two firms both make more profits in a (self-service, self-service) equilibrium. The conditions for the existence of different equilibria can be represented by the range of the explicit price for the self-service-only product in a (self-service, full-service) competition scenario. The existence of a (self-service, self-service) equilibrium relies on the prevention of downstream price cuts, which is realized by replacing economies of scale with constant returns to scale through completely outsourcing the service task to the customer. On the other hand, full-service firms dominate the market only when the self-service-only product fails to have enough market demand at a profitable price. If we consider that, in the long-run, the information about the other firm's choice between offering full-service and self-service-only product is known, it is possible for both types of service providers to coexist in a market equilibrium as each firm's best response strategy is always to position itself as different from its rival. Such coexistence of both types of firms is possible if the price for the self-service-only product is not too high or too low.

5 Summary and Discussion

With the queuing game model constructed herein, we have gained the following insights. First, we found that in the long-run, a firm's optimal strategy is either to require complete self-service or to provide full-service. In fact, a firm can minimize its profit by setting the proportion of the service task outsourced to the customer between zero and 100%. This result suggests that, theoretically, the two extreme formats of service delivery, complete self-service and full-service, will prevail rather than any intermediate combinations of the two. However, in reality, firms may have both types of service delivery channels available to its customers for many reasons. In fact, as we pointed out before, it is often necessary and important to make personal customer care or support available to the customers upon request when the service product is mainly delivered through self-service channels. It is also important to have self-service channels available to the customer to increase flexibility and convenience when the service is delivered primarily through employee service. Not doing so often results in poor service quality and customer dissatisfaction. This explains why Internet banks need to have live customer representatives to answer phone calls from customers who need personal attention or help, and why the traditional banks need to have websites and ATMs in addition to branches. Nevertheless, as a strategic choice for the design of a service

delivery process, firms should deliver a service either primarily through a self-service channel or primarily through an employee-based delivery mechanism. A firm needs to avoid a process design in which both the employee and the customer are almost equally involved, in which case the firm cannot gain the advantage of either format (the low cost associated with a self-service-only product and the high price that it can charge for providing full-service) and thus, can actually minimize its profit.

Secondly, though either complete self-service or full-service can be the most profitable choice in long-run for a single firm, when competition is taken into account, self-service may be the better choice since firms make more profits in a (self-service, self-service) equilibrium. Such an equilibrium actually creates a win-win situation for both the firms and the customer since the explicit price is actually lower. Substituting employee labor with customer self-service often results in significant cost-savings in labor and other costs as well as the capital investments related to employee services. However, we found that a (self-service, self-service) equilibrium may not exist if the downstream price cut, which often occurs in the presence of economies of scale, is too deep. By simultaneously outsourcing the service task completely to customers, the firms are able to transform economies of scale into constant returns-to-scale. Consequently, the incentive for a downstream price cut no longer exists, which essentially ensures the existence of a (self-service, self-service) equilibrium. This finding emphasizes that economies of scale provides a strong incentive for outsourcing, either to an outside supplier (Cachon and Harker 2002) or to the customer as in our model.

In addition, we also found that full-service providers can dominate markets only when self-service-only providers fail to charge their customers a profitable price. Consumers often demand some price compensation from the firm for their self-service and they often require a significant price difference between a self-service-only product and a full-service product in order to switch from full-service to self-service. When consumers are not willing to pay a price high enough for self-service-only products, the self-service-only firms either cannot make profits due to the low price they charge or fail to grab enough market share from the full-service providers if they raise their price. This may partially explain the failure of some self-service Internet business models in past several years: the lack of enough market demand for the self-service-only product at a profitable price. However, when customers' willingness to pay for the self-service product grows as they start to agree to pay for the reduction of congestion, convenience, and flexibility and some other unique features associated with self-service-only products, full-service providers may lose some market share to the self-service-only firms.

Finally, we found that both self-service-only firms and full-service firms can coexist in the market if customers either are not highly efficient nor highly inefficient, and the price for self-service-only product is neither too high nor too low. If customers are highly efficient, a full-service product may

not have much market demand; if customers are highly inefficient, self-service may not be a feasible solution for service delivery. In either case, one of the two types of firms cannot be sustained in the market. If the price for the self-service only product is so cheap that customers' willingness to pay for full-service is diminished, or the price is just too high to consider, one of the two types of firms are also driven out the market. Thus, in the long-run, when the explicit price for the self-service-only product is not too high or too low, it is possible to have a market equilibrium in which self-service-only firms and full-service firms are both available to the consumers. Though other factors may have also contributed to the coexistence of two types of service delivery channels in more and more service industries (e.g., the coexistence of Internet trading firms and traditional brokerage companies), we believe that the customer efficiency and price factors discussed herein have played significant roles.

In our model, we define ρ as the level of self-service, or the proportion of the workload outsourced to the customer. An alternative interpretation of ρ is the proportion of customers who are served through self-service channels. With this new definition, the total time that a customer of Firm i is expected to spend in order to receive the service remains as:

$$\rho_i e_i + \frac{1}{\mu_i - d_i(1 - \rho_i)}(1 - \rho_i). \quad (128)$$

That is, the probability for a customer to spend e_i amount of time is ρ_i and the probability for a customer to spend $\frac{1}{\mu_i - d_i(1 - \rho_i)}$ amount of time is $(1 - \rho_i)$, since each customer has the probability ρ_i of being served through the self-service channel and the probability $(1 - \rho_i)$ of being served through the employee service channel. Consistently, the average service rate for employee service remains as:

$$\mu_i = (g_i^{-1} + d_i)(1 - \rho_i) \quad (129)$$

while the average time that a customer is expected to spend to receive the service through employee channel is $g_i = \frac{1}{\mu_i - d_i(1 - \rho_i)}(1 - \rho_i)$. Thus, Firm i 's cost function remains unchanged:

$$C_i = n_i \mu_i = n_i (g_i^{-1} + d_i)(1 - \rho_i), \rho_i \in [0, 1] \quad (130)$$

Consequently, Firm i 's profit function remains unchanged:

$$\pi_i(f_i, g_i, \rho_i, f_j) = (f_i - \rho_i e_i - g_i) d_i - n_i (g_i^{-1} + d_i)(1 - \rho_i), \rho_i \in [0, 1] \quad (131)$$

Therefore, there exists a direct mapping of the two interpretations without any changes to the model. Since many service firms now have both self-service channels and employee service channels available to serve customers, the decision about what proportion of the customer population should

be served through the self-service channel is crucial for resource planning and, thus, has significant managerial implications. Our model makes it possible to explore how such a decision should be made in a competitive environment. A further extension with customer heterogeneity (different opportunity costs and efficiencies) taken into consideration in such decision making would bring even more managerial insights to this issue.

There are several potential extensions of our current study that will further our understanding of the issues regarding service coproduction, customer efficiency, and market competition. In particular, some of the assumptions we have made with the current model may be relaxed or adjusted in future research.

For example, we can relax the constraint that customer efficiency e_i is a pre-specified constant and consider e_i as a function of ρ_i ; i.e., $e_i(\rho_i)$ is convex increasing in ρ_i . This would suggest that customers become less efficient as the proportion of the workload they are assigned increases. Depending on how convex $e_i(\rho_i)$ is, there may or may not be an interior optimal ρ_i . If there is an interior optimal ρ_i , then the analysis of the game will be more complex. The results may generate some insights into the trade-off between the proportion of the workload outsourced to the customer and the efficiency of customer self-service and its impact on market competition. In addition, we may allow the firm to invest in reducing e_i and study how the investment in e_i may influence the competition. If we assume that e_i is independent of ρ_i , then the firm invests in e_i reduction only if it plans on choosing $\rho_i = 1$; i.e., invest in self service only if you plan to use only self service. Since the two competing firms would then have a constant returns to scale technology, this would be analogous to two competing firms investing in cost reduction.

Another possible extension is to allow for multiple customer types rather than to assume customer homogeneity in terms of their opportunity costs. In our current model, we assume that customers have uniform opportunity costs. In future research, we may relax this assumption and instead assume that some customers are willing to pay more for self-service than others due to different opportunity costs of time. As we have seen, the explicit price that customers are willing to pay for the self-service only product is the decisive factor for the existence of different market equilibria; this extension will take a further step toward incorporating customers' influence on pricing. Since in our model customers react only to the full price in the demand function rather than individual parts of the full price (the explicit market price, the price for self-service, and the price for employee service), the model and the major conclusions should remain structurally unchanged after relaxing the homogeneity assumption of customers' opportunity costs. However, as customers may now have different opportunity cost, the specific value of a firms' price and profits in a particular market equilibria may change. Consequently, the specific value of the range for customer efficiency in Theorem 1 and Theorem 2 and the ranges for the explicit price of the self-service-only

product in Theorems 3-5 may change as a result. Further exploration of this issue is on our future research agenda.

It is also worth exploring whether the major conclusions and results from this two-firm game model can be applied to a similar game with more than two firms; e.g., n firms that are symmetric in all respects except the self-service levels of their respective products. In a symmetric game, when all n firms set their self-service level at the same value, each firm would have the same market share or the same constant demand. The results of the game would then be similar to what we have in a two-firm symmetric game. However, if the firms choose different self-service levels and, therefore, the game is asymmetric, the results may depend on how the firms' full prices would influence each others' demand. In a simplified scenario, we may assume a linear demand function for a firm in which a firm's demand depends solely on the difference between its full price and that of the firm with the lowest full price in the market. The n -firm game then becomes analogous to $(n-1)$ two-firm games between the firm that charges the lowest full price and each of the other $(n-1)$ firms. These two-firm games will be structurally similar to the two-firm game herein with the added constraint that the two firms charge different full prices, which is consistent with the results from our current two-firm model for the asymmetric game. With such a simplified demand function, we would expect that the major results and conclusions in regard to the n -firm game will remain structurally similar to what we have from the two-firm game, although the specific values and ranges for the parameters and variables in the theorems may change. For a more complicated demand function for the n firms that consider the influence of the interactions between any two firms's full prices on each firm's demand, we may need make some structural changes in the model to incorporate these interactions and, therefore, this extension is left for future research.

Our study has made a first step toward understanding the relationships among self-service level, customer efficiency, and the market competition between firms that choose different channels to deliver its service, and how those relationships impact a firm's strategic choice of its service delivery process. The issues involved have become increasingly important with the rapid development of both self-service technologies and service operation models with customers' participating at all level in more and more situations. We expect further studies in this area to gain more insights into these important and timely issues facing service management researchers and practitioners across industries.

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