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Optimal Pricing Strategies for Open Source Support Providers*

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The market for commercial open source software (OSS) has been rapidly growing with the proliferation of OSS. One way to commercialize OSS is the support model, which has been adopted by leading OSS firms such as Red Hat and JBoss. Despite the growing interest in OSS commercialization, little research has provided OSS support providers with a pricing guideline. In this paper, we examine the optimal pricing strategies for OSS support providers. Our benchmark is a monopoly case in which we investigate a startup software vendor's incentive to choose the OSS support regime over the proprietary one. Then we extend the model to a duopoly case in which OSS under the support regime competes against proprietary software. We characterize the conditions under which the OSS support model is viable under competition. We believe that our results offer insights to the OSS vendors who consider commercializing their OSS with a support model.

Keywords : IS Development and Operations, Open Source Software, Technology Commercialization, Pricing, Economic Modeling

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Ⅰ. Introduction

Recent proliferation of open source software (OSS) attracts immediate attention of the providers of OSS that reached a critical mass to commercializing their OSS products. Despite the long-standing impression that OSS is free, a significant growth in OSS commercialization has been observed in reality in the past decade. Various models have been used for OSS commercialization, including dual-licensing and bundling with hardware solution [Dahlander, 2007]. Another business model for commercial OSS is a support model under which OSS is distributed freely, while the OSS vendor sells support services to customers in need. Red Hat Enterprise Linux is a well-known example of the OSS support model under which Red Hat makes profit by selling subscriptions to firm-level customers who get support services for Red Hat Linux. JBoss, a market-leading web application server, is another example of the successful OSS support model.

Practitioners who are not positive toward OSS commercialization under the support regime mention the following disadvantages that any OSS support providers may face. First, due to its free distribution, profit can be made only through customers who are willing to pay for the support services. Second, it is often observed that most of popular OSS, either commercial or free, faces competition against well-established proprietary software. For example, Red Hat competes against Microsoft in the operating systems software market, and JBoss is splitting the web application server market with IBM Web Sphere. Given these two reasons, i.e., limited size of profitable customer pool and competition against proprietary software, viability of the OSS support model was often questioned. Despite this skeptical view, some OSS vendors, such as Red Hat and JBoss, have proven that the OSS support model is a viable option to commercialize OSS. Accordingly, practitioners are interested in identifying key drivers of the successful OSS commercialization [Vaughan-Nichols, 2005].

Reflecting the trend in the real-world software market, OSS commercialization is becoming a popular research topic among academics as well, but a number of questions still remain unanswered. In this paper, we examine the viability of the OSS support model. Specifically, we identify the key success factors of the OSS support model such as flexibility benefits from OSS and customers' technical savviness. We examine two different market structures: monopoly and duopoly. The benchmark is a monopolistic market in which a single software vendor makes its business model choice between proprietary and OSS support regimes. We investigate whether the monopolistic software vendor has incentive to choose the OSS support regime over the proprietary one. The monopoly case is not uninteresting in the context of the software market due to two reasons. First, a number of real-world software markets have a monopolistic structure. Second, the findings from the monopoly case may provide startup firms with practical insights. Then we enrich our model by extending to a duopolistic market where an OSS vendor competes against a proprietary software vendor. We analyze the pricing strategies of both firms and investigate whether the OSS vendor is able to survive the competition.

Our findings indicate that the OSS support model is outperformed by the proprietary model in the monopoly case. This result is not surprising since the OSS support model only targets the non-tech-savvy customers who may need support while the proprietary software can be purchased by any customers, including tech-savvy ones. Thus, a startup software vendor may not want to consider the OSS support model as a venue for its business model. In a duopolistic market, the proprietary software vendor's optimal strategy is setting price at the level of the marginal cost for OSS support so that the OSS vendor loses incentive to join the market. Then we consider quality asymmetry as a possible driver of the viability of the OSS support model. We find that the OSS vendor survives duopolistic competition when OSS comes with higher value than proprietary software. More interestingly, even when OSS is with worse quality than proprietary software, the OSS vendor makes thin but positive profit, which can be explained by market expansion due to a variety of customer choices. This result implies that differentiating quality is one possible option for OSS vendors who consider commercializing their OSS under the support regime.

This paper has practical value in that we model the factors influencing the value of OSS with a support model and characterize the conditions under which the OSS support model is viable. The findings provide OSS vendors who plan to commercialize their software as well as proprietary software vendors who are facing potential threat from OSS with the pricing and strategic guidelines. Next, we review the literature and discuss the academic value of the research.

Ⅱ. Literature Review

On the modeling side, our work is based on the literature on information goods pricing. Various pricing strategies have been identified and discussed for information goods in the domain of information systems. Such strategies include versioning [Bhargava and Choudhary, 2001; Bhargava *et al*., 2012; Sundararajan, 2004], bundling [Bakos and Brynjolfsson, 1999; Hitt and Chen, 2005], and price discrimination [Choudhary *et al*., 2005; Dewan *et al*., 2003].

A research stream that is more closely related to our paper is the economics of OSS. Until recently, the most popular theme in the OSS literature was individual software developers' motivation for OSS project participation. A number of studies provide explanations for OSS developers' participation which is often not compensated with monetary benefit. Research has been done from various perspectives, including economics [Lee and Kim, 2012; Lerner and Tirole, 2001; 2002] and behavioral sciences [Franke and von Hippel, 2003; Roberts *et al*., 2006; Shah, 2006; von Hippel and von Krogh, 2003]. An emerging research stream in OSS views OSS community as a network and analyzes the structure of the OSS network with various methodologies. For example, Oh and Jeon [2007] borrow Ising theory from Physics to study membership herding observed in the OSS network. Singh and Tan [2011] study the formulation and stabilization of OSS networks when individual developers are heterogeneous. Singh *et al*. [2011] investigate the learning dynamics in the OSS community, ground on a hidden Markov model.

The most relevant research stream to our work is modeling competition between proprietary software and OSS. Early studies focus on the impact of free OSS on the software competition, examining various aspects, such as quality [Raghunathan *et al*., 2005], dynamic duopoly [Casadesus-Masanell and Ghemawat, 2006], two-sided market with network effects [Economides and Katsamakas, 2006] and strategic issues [Zhu and Zhou, 2011]. While most studies in this stream assume that OSS is freely distributed, Choudhary and Zhou [2007] examine the impact of commercial OSS on proprietary software. They develop an analytical model of mixed duopoly competition and find the conditions under which proprietary software vendor has more incentive to improve quality with OSS than without.

This paper aims to make contributions to the OSS literature by examining the viability of the OSS support model which has not been studied deeply by academics despite the growing interest in OSS commercialization. Our model captures two dimensions of customer heterogeneity, one of which is technical savviness that comes to play when customers choose OSS. Consideration of technical savviness that differentiates OSS from proprietary software at the customer utility level is contributive from a modeling perspective. Finally, our findings provide the startup software firms who are making business model choice and the established proprietary software firms who face competition with OSS, with strategic and pricing guidelines.

Ⅲ. Overview of Model

In this section, we introduce the model setting with which we investigate the optimal pricing strategy for an OSS support provider. Motivated by reality, this paper considers OSS that is freely distributed while relevant support service is offered for a fee. One example is Red Hat Enterprise Linux, which makes profit through support services. Another example is JBoss that offers a package of services for JBoss Enterprise Middleware, including subscription, consulting, training and certification. Since the product of our interest is software that is a conventional example of information goods, we assume zero marginal cost of production, consistent with the existing literature [Arora *et al*., 2006; Bhargava *et al*., 2012]. However, the support service providers incur positive marginal cost for support including labor cost.

Customers in our paper are firms, not individual software users. We model customer heterogeneity in two dimensions: valuation and technical savviness. Consistent with the existing literature, customers are characterized by their value, v, implying that different customers evaluate the same software differently. This is reasonable since the value of software is realized in the business functions of the customers who have different business needs. v is assumed to be uniformly distributed on [0, 1]. This simplification of reality with uniform distribution is common in applied economics literature such as information systems [Arora *et al*., 2006] and operations management [Kim *et al*., 2011]. Another dimension of heterogeneity is customers' technical savviness. We consider two types of customers: (i) tech-savvy firms, denoted with T, who have strong internal IT management team capable of managing and customizing OSS and (ii) non-tech-savvy firms, denoted with N, who lack IT skills to enjoy flexibility benefit from OSS and suffer from maintenance of OSS. The non-tech-savvy firms are potential customers of OSS support services since the benefit of purchasing third-party service may outweigh the cost for in-house OSS management. We normalize the size of the customer pool to 1 where a proportion is T and the remaining 1 -α proportion is N.

When a customer chooses proprietary software, there is no flexibility benefit or support cost. One may argue that users of proprietary software also enjoy some flexibility benefit and/or they incur support cost. Reflecting reality, what we model in this paper are relative flexibility benefit and support cost from OSS while normalizing both factors from proprietary software to be zero. Thus, a proprietary software customer's utility is determined by the valuation and the price only. We use p to denote price while P in the subscript represents proprietary software. A customer enjoys the following utility from proprietary software:

$$u_P = v - p_P \tag{1}$$

When a customer purchases OSS, tech-savinness comes into play. Tech-savvy customers customize OSS to meet their own business needs and enjoy flexibility benefit, without incurring any support, implying that internal maintenance is not a significant burden for this type of customers. On the other hand, non-tech-savvy customers are, by definition, incapable of customizing the OSS and they suffer from support and maintenance. Thus, as far as the provider offers reasonable price lower than the support cost the non-tech-savvy customers incurs, they have incentive to buy support service from the provider. Thus, the non-tech-savvy customers are the potentially profitable customers of the OSS support service. Reflecting what happens in the real-world software support service market where the subscribers are entitled to receive the service until the problem is resolved, our model assumes that the non-tech- savvy customers who purchase support service no longer suffer from any internal maintenance issues. Under this business model, the software itself is distributed at no charge. The monopolist makes profit by selling its support service to the customers who want it. Let p_O be price for the OSS support service and β be flexibility benefit from OSS, then the net benefits for a tech-savvy (T) and a non-tech-savvy (N) customer can be written as

$$\begin{aligned} u_{OT} &= v + \beta \\ u_{ON} &= v - p_O \end{aligned} \tag{2}$$

Ⅳ. Benchmark: The Monopoly Case

We first analyze the monopoly case as benchmark. We examine a monopolistic software vendor's optimal business model choice between proprietary and OSS support, and find the optimal price with each business model. The monopoly case is not uninteresting since it is hard to expect a business model to be viable under competition if it is not viable under monopoly. Also, characterizing the conditions under which a monopolist chooses the OSS support model provides insights to startup software vendors who consider commercializing their OSS products. If a monopolistic software vendor chooses a proprietary model, the expected demand becomes

$$x_P = \int_{p_P}^{1} 1 dv = 1 - p_P \tag{3}$$

which leads to the profit

$$\pi_P = x_P\, p_P = (1 - p_P) p_P \tag{4}$$

Solving for the first order condition leads to the optimal price under a proprietary model, $p_P^* = \frac{1}{2}$, at which the expected profit becomes $\pi_P^* = \frac{1}{4}$.

If a monopolistic software vendor follows the OSS support regime, it can expect the demand for the support service as

$$x_O = (1-\alpha)\int_{p_O}^{1} 1 dv = (1-\alpha)(1-p_O) \qquad (5)$$

and the profit as

$$\pi_O = x_O(p_O - c_O) = (1-\alpha)(1-p_O)(p_O - c_O) \quad (6)$$

where c_O is the marginal cost for support. Solving for the profit maximization problem yields the optimal price for support as $p_O^* = \frac{1+c_O}{2}$ at which the maximum profit becomes $\pi_S^* = \frac{1}{4}(1-\alpha)(1-c_O)^2$. The comparison of the optimal prices, i.e., p_P^* and p_O^* leads to the following Proposition.

Proposition 1: *A monopolistic software vendor charges higher price for OSS support than for proprietary software* $(p_O^* > p_P^*)$.

Proposition 1 indicates that the monopolistic software vendor charges higher price under the OSS support regime than under the proprietary regime. Since the monopolist loses a segment of tech-savvy customers when it chooses the OSS support model over the proprietary model, the monopolist wants to compensate it by charging high price. This may contradict what is happening in reality since customers cite cost advantage as number one reason to adopt OSS. The lack of monopolistic commercial OSS in reality could be explained by insufficient number of non-tech-savvy customers who are willing to pay for the support. We next compare profits to investigate whether a monopolistic software vendor has incentive to choose an OSS support model over a proprietary model. We then characterize the conditions for the OSS support model to be viable under monopoly if there is any.

Proposition 2: *A monopolistic software vendor's profit is lower with an OSS support model than with a proprietary model* $(\pi_O^* < \pi_P^*)$.

Proof: See the Appendix.

Proposition 2 shows that the proprietary model brings higher profit to a monopolistic software vendor than the OSS support model. This result is consistent with reality in that a monopolistic OSS vendor with a support model is rare. There are two factors that explain why OSS support model is not viable under monopoly: marginal cost for support and smaller segment of profitable customers for OSS. While the marginal cost is zero under the proprietary regime, it is not under the OSS support regime. Thus, combined with a smaller number of profitable customers, the monopolist's profit is always lower with the OSS support model than with the proprietary model. This implies that for start-up software companies, proprietary regime is a better choice than OSS regime as often observed in the real-world software market. Then an interesting question becomes under what circumstances the OSS support model is viable. We consider competition as a possible driver of the viable commercial OSS, and examine the duopoly case in which OSS competes against proprietary software.

V. The Duopoly Case: OSS with Support Versus Proprietary Software

In reality, many OSS products, commercial or free, compete with proprietary software products. Commercial OSS with a support model is not an exception. For example, Red Hat who makes profit by selling its support service, called, Red Hat Enterprise Linux, competes against Microsoft Windows in the operating systems software market. JBoss, another leading OSS support provider, splits the web application server market with IBM. Thus, examining the impact of duopolistic competition between an OSS support provider and a proprietary software vendor is important to understand the viability of the OSS support model. In this section, we enrich our model by considering a duopolistic competition. We use Bertrand model with product differentiation as a basis while considering customer heterogeneity in two dimensions is a unique aspect of our model. We investigate whether the OSS support model is viable under competition and characterize the corresponding conditions.

5.1 Symmetric Quality

We start with examining a duopolistic market where proprietary software and OSS compete against each other with the same value, represented with parameter v. Recall that a customer enjoys the following benefit from proprietary software:

$$u_P = v - p_P \tag{7}$$

Also recall that utility of a customer who chooses OSS and buys support service is

$$\begin{aligned} u_{OT} &= v + \beta \\ u_{ON} &= v - p_O \end{aligned} \tag{8}$$

We first consider a tech-savvy (T) customer's choice. Note that a type-T customer does not incur any support cost since maintenance is taken care of by its in-house IT management team that is also capable of customizing OSS. On the other hand, proprietary software is costly while delivering not much flexibility benefit compared to OSS, which we normalize to zero. Note that $u_P = v - p_P < u_{OT} = v + \beta$, implying, a type-$T$ customer will always choose OSS over proprietary software. Therefore, the only source of profit is the segment of non-tech-savvy (N) customers. The demand levels are determined by the prices offered by both software vendors. That is, the vendor who sets a lower price takes all customers while the other is left with zero demand. Under duopoly, software vendors make the following profits:

$$\begin{aligned} \pi_P &= (1-\alpha) x_P p_P \\ \pi_O &= (1-\alpha) x_O (p_O - c_O) \end{aligned} \tag{9}$$

Since the OSS vendor incurs positive marginal cost to provide support, the marginal cost sets the lower bound for the price for OSS support, i.e., $p_O \geq c_O$. Suppose that the proprietary software vendor sets price below the OSS vendor's marginal cost, i.e., $p_P < c_O$. Then the proprietary software vendor still has a room to make more profit by increasing price up to the level of OSS vendor's marginal cost while still serving all customers. Thus, $p_P < c_O$ is not an equilibrium. Now, consider the case where both software vendors set prices strictly above c_O. When $p_P > p_O > c_O$, the proprietary software vendor has incentive to lower its price to somewhere between p_O and c_O, so that it can serve all customers. On the other hand, when $p_O > p_P > c_O$, the OSS vendor has the same incentive, i.e., setting its price between p_P

and c_O. Thus, both firms' charging prices above c_O is not an equilibrium either. Then, we examine the only case left, that is, $p_P = p_O = c_O$. When the proprietary software vendor offers price at c_O the only choice the OSS has is charging its price at the level of marginal cost. Then the OSS vendor makes zero profit and the proprietary software vendor dominates the entire market. Therefore, the equilibrium prices are

$$p_P^* = p_O^* = c_O \tag{10}$$

Then the proprietary software vendor makes profit as

$$\pi_P^* = (1-\alpha)(1-c_O)c_O \tag{11}$$

When the marginal cost for OSS support is higher than $p_P^{Monopoly} = \frac{1}{2}$, the proprietary software vendor charges the monopoly price, i.e., $p_P^{Duopoly} = p_P^{Monopoly} = \frac{1}{2}$. The results are summarized in the following proposition.

Proposition 3: *The OSS support model is not viable under duopolistic competition with proprietary software. At equilibrium, the proprietary software vendor sets its price at the level of the marginal cost for OSS support* $(p_P^* = c_o)$, *which prevents the OSS vendor from earning positive profit. When the OSS vendor incurs a relatively high marginal cost, the proprietary software vendor can even charge monopoly price.*

Proposition 3 indicates that the OSS vendor is not able to survive a duopolistic competition with a proprietary vendor. The proprietary vendor takes a cost advantage and plays an aggressive pricing strategy so that the OSS vendor is left with zero profit. Given the asymmetric cost structure, the OSS support model is never viable under competition. This result provides insights that explain a slow growth of the commercial OSS market despite the massive attention paid to OSS commercialization. Then the interesting questions become how some OSS vendors in reality have been successful in commercializing their OSS with the support model.

One factor that might contribute to the viability is value difference, i.e., the value customers perceive from OSS is not same as the value from proprietary software. It could be difference in functionality (e.g., more features), ease of use (e.g., more user-friendly interface), and security (e.g., less security holes or bugs). Since the major source of value is software quality, we use the terms, value and quality interchangeably. We investigate how this quality asymmetry affects the dynamics of competition. Specifically, we are interested in knowing whether quality asymmetry leads to viability of the OSS support model. We assume the quality difference level is exogenous, so we call it quality asymmetry, not quality differentiation which is often firms' endogenous decision. This is a reasonable assumption within the scope of our paper since we examine two software firms, both of which already have products at a mature stage of their development cycle. Also, for an OSS vendor, quality level is often not its choice. It is determined by factors not under the vendor's control, for example, individual developers' participation and contribution.

5.2 Asymmetric Quality: Superior OSS

In this section, we examine the case where OSS offers higher value than proprietary software. Our question of interest is whether the value advantage attracts the customers with high v so as to make the OSS support model viable. We capture the level of quality difference between two software products with parameter δ. Given that OSS provider is often not capable of determining the quality of software since the level of programmers' voluntary participation is the determinant of the OSS quality, we assume δ to be exogenous, i.e., not the OSS vendor's decision. In the presence of quality asymmetry, the OSS customer's utility can be represented as

$$\begin{aligned} u_{OT} &= \delta v + \beta \\ u_{ON} &= \delta v - p_O \end{aligned} \tag{12}$$

Recall that OSS provides higher value than proprietary software, i.e., $\delta > 1$. In this case, all tech- savvy customers will choose OSS since they are the ones who choose OSS even with the same value as proprietary software. Technically, $u_{OT} - u_P = \delta v + \beta - v + p_P = (\delta - 1)v + \beta + p_P > 0$. Thus, both software vendors compete for non-tech-savvy customers. A non-tech-savvy customer will choose OSS if $u_{ON} - u_P = \delta v - p_O - v + p_P = (\delta - 1)v - p_O + p_P > 0$. Note that a non-tech-savvy customer's software choice can be summarized as follows:

$$\begin{aligned} &\frac{p_O - p_P}{\delta - 1} < v < 1 &&: \text{OSS} \\ &p_p < v < \frac{p_O - p_P}{\delta - 1} &&: \text{Proprietary SW} \\ &0 < v < p_P &&: \text{No SW} \end{aligned} \tag{13}$$

The demands for both software vendors are determined as

$$\begin{aligned} x_P &= \int_{p_P}^{\frac{p_O - p_P}{\delta - 1}} dv = \frac{p_O - p_P}{\delta - 1} - p_P \\ x_O &= \int_{\frac{p_O - p_P}{\delta - 1}}^{1} dv = 1 - \frac{p_O - p_P}{\delta - 1} \end{aligned} \tag{14}$$

Then the proprietary software makes profit as

$$\pi_P = (1-\alpha) x_P p_P = (1-\alpha)\left(\frac{p_O - p_P}{\delta - 1} - p_P\right) p_P \tag{15}$$

On the other hand, the OSS vendor's profit

$$\begin{aligned} \pi_O &= (1-\alpha) x_O (p_O - c_O) \\ &= (1-\alpha)\left(1 - \frac{p_O - p_P}{\delta - 1}\right)(p_O - c_O) \end{aligned} \tag{16}$$

Jointly maximizing profits lead to the following optimal prices:

$$\begin{aligned} p_P^* &= \frac{\delta - 1 + c_O}{4\delta - 1} \\ p_O^* &= \frac{2\delta(\delta - 1 + c_O)}{4\delta - 1} \end{aligned} \tag{17}$$

Then the proprietary and OSS vendors make profits as

$$\begin{aligned} \pi_P^* &= \frac{(1-\alpha)\delta(\delta - 1 + c_O)^2}{(4\delta - 1)^2(\delta - 1)} \\ \pi_O^* &= \frac{(1-\alpha)(2\delta(\delta - 1) - (2\delta - 1)c_O)^2}{(4\delta - 1)^2(\delta - 1)}. \end{aligned} \tag{18}$$

A further analysis leads to Proposition 4.

Proposition 4: *Suppose that the OSS offers higher quality than the proprietary software* $(\delta > 1)$. *OSS support price increases with the quality difference level while proprietary software price increases (decreases) as the quality difference level increases when the* *marginal cost for OSS support is small (large).*

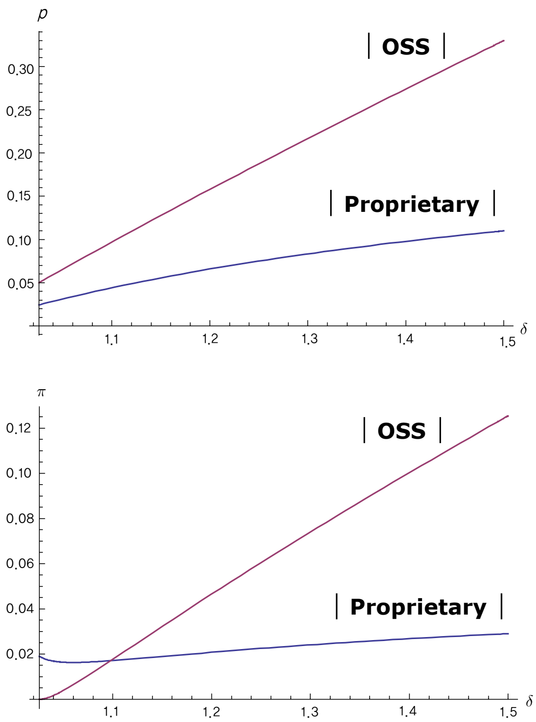
Proof. See the Appendix.

Proposition 4 shows that the OSS support model is viable under duopoly when it provides higher value to customers than proprietary software. This result implies that OSS vendors should value research and development since offering superior quality is a key driver of the viability of the OSS support model. Adding value to OSS turns to be one way to overcome the cost disadvantage. Our findings indicate that OSS support price increases with the level of quality difference. Interestingly, the impact of quality difference on the proprietary software price depends on the marginal cost for OSS support. When the marginal cost for OSS support is in a reasonable range, proprietary software price increases with the level of quality difference. However, when the marginal cost for OSS support is extremely high, more than 75 percent of the highest possible valuation, the proprietary vendor reduces price as quality gap increases. The intuition is as follows. With extremely high marginal cost, the OSS vendor has no choice but targeting customers with very high valuation. Thus, the proprietary vendor may be better off by setting price low so that it can serve all of the remaining customers. <Figure 1> illustrates the impact of quality difference on optimal prices and profits in the presence of reasonable marginal cost for OSS support.

Proposition 5: *When the OSS offers higher quality than the proprietary software* $(\delta > 1)$, *the OSS support model is viable under duopoly* $(\pi_O^* > 0)$. *Both the OSS and the proprietary software vendors' profits increase (decrease) with the quality difference level when the marginal cost for OSS support is small (large).*

Proof: See the Appendix.

Proposition 5 summarizes the impact of quality difference on prices and profits. <Figure 1> shows that, in the specified parameter space, both OSS and proprietary software prices increase with the level of quality difference with OSS at higher rate. This steeper price increase of OSS can be explained by its superiority in quality. It is not surprising to see that OSS is viable with superior quality. What is more interesting is the dynamics among profit, quality difference and marginal cost for support. <Figure 1> shows that proprietary software vendor makes higher profit than OSS vendor when the level of quality difference is low. Due to its installed based in period 1 and cost



<Figure 1> Impact of Quality Asymmetry on Prices and Profits (Superior OSS, $\alpha = 0.2,\ c_O = 0.05$)

advantage, the proprietary software vendor can outperform the OSS vendor even with lower-quality product when OSS is not sufficiently better than proprietary software. However, when the quality difference level reaches a certain threshold, OSS vendor's profit outweighs proprietary software vendor's profit. Interestingly, both software vendors' profits increase with the quality difference level only when the marginal cost for OSS support is relatively small. This result implies that not only the OSS vendor but also the proprietary software vendor is better off with high level of quality difference as long as supporting customers is not too costly for the OSS vendor. Next, we examine the opposite case in which OSS comes with worse value than proprietary software, which may be often observed in reality.

5.3 Asymmetric Quality: Inferior OSS

Due to the free distribution of OSS, people often expect quality deficiency from OSS compared to proprietary software. This may or may not be true as many academics and practitioners have argued for a long time. Certainly, this case where OSS is inferior to proprietary software is a possibility, which is worthwhile to examine. Recall that the OSS support model is not viable under duopoly when OSS comes with the same value as proprietary software and one way to survive the competition is offering higher value. Then an interesting question becomes what if OSS offers lower value than proprietary software. Can inferior OSS attract customers while OSS with the same quality as proprietary software cannot? We aim to answer these questions. Suppose that OSS provides lower value than proprietary software, i.e., $0<\delta<1$. Consider the tech-savvy customers. Unlike previous cases where all tech-savvy customers choose OSS, some tech-savvy customers with high valuation will choose proprietary software when $u_P-u_{OT}=v-p_P-\delta v-\beta=(1-\delta)v-(p_P+\beta)>0$. A tech-savvy customer's choice can be summarized as follows:

$$\frac{p_P+\beta}{1-\delta}<v<1 \text{ : Proprietary SW} \tag{19}$$

$$0<v<\frac{p_P+\beta}{1-\delta} \text{ : Oss without Support}$$

Thus, the demands from T-segment become

$$x_{PT}=\int_{\frac{p_P+\beta}{1-\delta}}^{1}dv=1-\frac{p_P+\beta}{1-\delta} \tag{20}$$

$$x_{OT}=0$$

Now, consider the non-tech-savvy customers. A non-tech-savvy customer's choice will be OSS when $u_{ON}-u_P=\delta v-p_O-v+p_P=(\delta-1)v-p_O+p_P>0$. Thus, a non-tech-savvy customer's software choice can be summarized as follows:

$$\frac{p_P-p_O}{1-\delta}<v<1 \text{ : Proprietary SW} \tag{21}$$

$$p_O<v<\frac{p_P-p_O}{1-\delta} \text{ : OSS with Support}$$

$$0<v<p_O \text{ : No SW}$$

Thus, the demands from N-segment become

$$x_{PN}=\int_{\frac{p_P-p_O}{1-\delta}}^{1}dv=1-\frac{p_P-p_O}{1-\delta} \tag{22}$$

$$x_{ON}=\int_{p_O}^{\frac{p_P-p_O}{1-\delta}}dv=\frac{p_P-p_O}{1-\delta}-p_O$$

Then the proprietary software makes profit as

$$\pi_P = (\alpha x_{PT} + (1-\alpha)x_{PN})p_P \tag{23}$$
$$= \left(\alpha\left(1-\frac{p_P+\beta}{1-\delta}\right)+(1-\alpha)\left(1-\frac{p_P-p_O}{1-\delta}\right)\right)p_P$$

The OSS vendor earns the following profit:

$$\pi_O = (1-\alpha)x_{ON}(p_O - c_O) \tag{24}$$
$$= (1-\alpha)\left(\frac{p_P-p_O}{1-\delta}-p_O\right)(p_O-c_O)$$

Solving the joint maximization problem leads to the following optimal prices:

$$p_P^* = \frac{(2-\delta)(2(1-\alpha\beta-\delta)-(1-\alpha)c_O)}{7+\alpha-4\delta} \tag{25}$$
$$p_O^* = \frac{1-\alpha\beta-\delta+2(2-\delta)c_O}{7+\alpha-4\delta}$$

The profits the software vendors make become

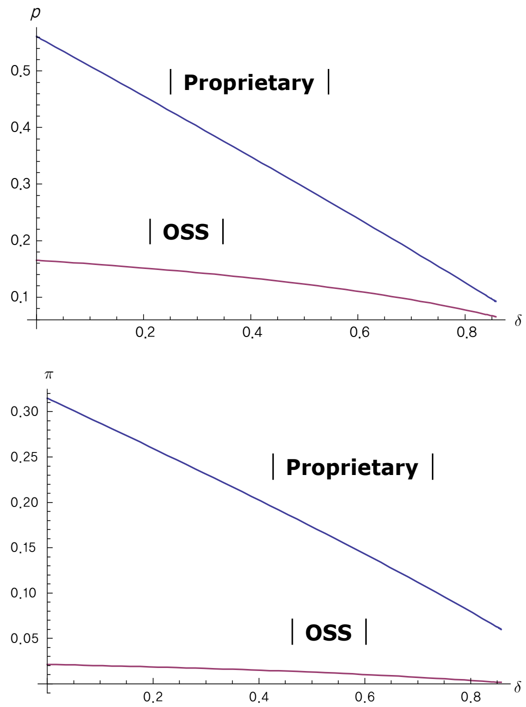
$$\pi_P^* = \frac{(2-\delta)^2(2(1-\alpha\beta-\delta)+(1-\alpha)c_O)^2}{(7+\alpha-4\delta)^2(1-\delta)} \tag{26}$$
$$\pi_O^* = \frac{(1-\alpha)(2-\delta)(1-\alpha\beta-\delta+(2\delta-\alpha-3)c_O)^2}{(7+\alpha-4\delta)^2(1-\delta)}$$

A further analysis leads to Proposition 5.

Proposition 6: *When the OSS offers lower quality than the proprietary software* $(0<\delta<1)$, *the OSS support model is viable under duopoly* $(\pi_O^*>0)$. *Both OSS support price and proprietary software price increase with the quality differentiation level.*

Proof: See the Appendix.

The results indicate that the OSS support model becomes viable even when the OSS vendor offers inferior quality. While the result seems counter-intuitive, it can be the outcome of market expansion due to a variety of choice. When there is a single quality option available in the market, tech-savvy customers always choose OSS since they do not incur any expense. However, when there are two quality choices, high quality from proprietary software and low quality from OSS, some tech-savvy customers who are willing to pay for the extra value, will buy proprietary software. Thus, the size of profitable customer pool expands. Given the expansion of the market, the OSS vendor is able to attract some non-tech-savvy customers and make positive profit. <Figure 2> illustrates the impact of quality difference on the prices and profits.



<Figure 2> Impact of Quality Asymmetry on Prices and Profits(Inferior OSS, $\alpha=0.2, c_O=0.05, \beta=0.05$)

While the pattern of increase in price with quality difference level is similar to the previous case illustrated in <Figure 1>, the impact of quality difference on profits is counter-intuitive. Interestingly, OSS vendor's profit is thin but positive, implying that the OSS support model is viable, with inferior product while it cannot survive with the equivalent quality. This finding has significant managerial implications to OSS vendors who want to commercialize their OSS by selling support services. Quality control is often not easy for OSS vendors since OSS quality is determined by participating programmers' effort level. However, what OSS vendors can do is to decide when to commercialize their OSS. The results imply that it may be optimal for an OSS vendor to commercialize its OSS at the early stage if it is expected that outweighing proprietary software's value will never happen. The profit for the OSS support provider is actually higher with worse quality as illustrated in <Figure 2>.

Ⅵ. Managerial Implications

A growing interest in OSS commercialization raises questions about the optimal model choice for commercial OSS and the key drivers of the successful OSS business models. Given that the OSS commercialization is considered to be at the early stage, many questions still remain unanswered. One of such questions is viability of the OSS support model under which the software package is freely distributed while the OSS vendor sells its support services to the customers in need. Considering the free distribution of the software, practitioners have been skeptical about the OSS support model as a viable model choice of OSS commercialization. Nevertheless, some OSS vendors, such as Red Hat and JBoss, have been successful with the support model, even under competition with established proprietary vendors, including Microsoft and IBM.

Benefiting the game-theoretic modeling method, we aim to answer questions around OSS commercialization, including viability of OSS support model and the key drivers of success. We first examine a monopolistic software vendor's choice between a proprietary regime and an OSS regime. The result indicates that the monopolistic vendor does not have incentive to choose the OSS support regime over the proprietary regime. This outcome explains why it is hard to find real-world cases of commercial OSS with a support model under monopoly. While there exist commercial OSS examples in reality, most of them are under competition. Thus, we came up with a presumption that competition might play a role in OSS commercialization. We examine the impact of competition on the viability of the OSS support model when OSS and proprietary software vendors provide equivalent quality. It turns out that the OSS support provider cannot survive the duopolistic competition since the proprietary software firm plays a pricing strategy to prevent the OSS from sharing the market. Due to the inevitable marginal cost and the limited number of profitable customers, the OSS support provider is not able to attract customers given the proprietary software vendor's aggressive pricing. This implies to practitioners who commercialize OSS that the support model will never be a viable option when OSS and proprietary software provide identical value.

A naturally following question was whether quality asymmetry can lead to viable OSS commercialization under competition. Our analysis shows that, with superior quality, OSS creates a market for the high-value customers. What is interesting is the opposite way of quality differentiation, i.e., OSS comes with worse quality than proprietary software. The result shows that the OSS support model is viable with this way of quality differentiation as well, that is, the OSS vendor makes thin but positive profit. This leaves counter-intuitive yet meaningful implications to practitioners. Compared to a proprietary software firm, quality is often not an OSS vendor's decision. Thus, what OSS can control is timing of commercialization. Our result indicates that higher quality gap may bring higher profit to the OSS support provider. When the OSS vendor realizes that the quality of OSS will never outclass the quality of the completing proprietary software, early introduction of the commercial support service may be the right strategic choice.

Ⅶ. Concluding Remarks

Responding the needs from the market to answer questions around OSS commercialization, this paper examines the viability of the OSS support model. We aim to make contributions to the literature by identifying the factors that affect viability of the OSS support model and characterizing the conditions that lead to successful commercialization of OSS. Our model considers the factors that are generic to OSS customers such as flexibility benefit and technical savviness, which is contributive from a modeling perspective. Finally, our findings have practical value and provide strategic pricing guidelines to the OSS vendors who consider adopting the support model as a way to commercialize OSS.

Our analysis has several limitations which provide future research with directions. First, we consider quality difference as an exogenous factor. In reality, quality control is often difficult for OSS vendors since it is determined by individual developers' participation level, which is out of the project leader's control. Thus, we decide to focus on pricing decisions of software vendors who already have established products. However, making quality choice as an endogenous choice of software vendors grounded on the models in the quality differentiation literature will certainly enrich the model and derive further insights. Second, we model the software vendors' decision in a single period. It will be an interesting venue to examine software vendors' entry decision in a multi-period game. Studying the switching behavior of the customers in this extended model will be another interesting topic for future research.

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⟨Appendix⟩

Proof of Proposition 2

Note that $\pi_O^* - \pi_P^* = \frac{1}{4}(1-\alpha)(1-c_O)^2 - \frac{1}{4}$. The marginal cost is bounded by price, i.e. $c_O \le p_O^* = \frac{1+c_O}{2}$. Therefore, $0 < c_O \le 1$. Since $\alpha \in [0, 1]$, we have $0 \le (1-\alpha)(1-c_O)^2 < 1$. Therefore, $\pi_O^* - \pi_P^* < 0$. ***QED.***

Proof of Proposition 4

Note that $\frac{\partial p_O^*}{\partial \delta} = \frac{2(1-c_O)+4\delta(2\delta-1)}{(4\delta-1)^2} > 0$ and $\frac{\partial p_P^*}{\partial \delta} = \frac{3-4c_O}{(4\delta-1)^2}$. Thus, $\frac{\partial p_P^*}{\partial \delta} > 0$ when $c_O < \frac{3}{4}$ while $\frac{\partial p_P^*}{\partial \delta} < 0$ when $c_O > \frac{3}{4}$, which completes the proof. ***QED.***

Proof of Proposition 5

The first derivative of the OSS vendor's profit with respect to quality difference is

$$\frac{\partial \pi_O^*}{\partial \delta} = \frac{(1-\alpha)(2(\delta-1)\delta-(2\delta-1)c_O)(2(\delta-1)(2+\delta(4\delta-3))+(5+2\delta(4\delta-5))c_O)}{(\delta-1)^2(4\delta-1)^3}$$

Since $\delta > 1$ and $\alpha < 1$, the sign of $\frac{\partial \pi_O^*}{\partial \delta}$ is determined by the two terms that include the marginal cost, i.e., $(2(\delta-1)\delta-(2\delta-1)c_O)(2(\delta-1)(2+\delta(4\delta-3)+(5+2\delta(4\delta-5))c_O)$. Note that $2\delta-1>0$. Let $f_1 = 5+2\delta(4\delta-5)$. Since $f_1(\delta=1)=3>0$ and $\left.\frac{\partial f_1}{\partial \delta}\right|_{\delta=1} = 6 > 0$, we have $f_1 > 0$. Solving for $\frac{\partial \pi_O^*}{\partial \delta} = 0$ with respect to c_O leads to the single positive solution, $c_O^* = \frac{2\delta(\delta-1)}{2\delta-1}$. Therefore,

$$\frac{\partial \pi_O^*}{\partial \delta} > 0 \text{ when } c_O < \frac{2\delta(\delta-1)}{2\delta-1},$$
$$\frac{\partial \pi_O^*}{\partial \delta} < 0 \text{ when } c_O > \frac{2\delta(\delta-1)}{2\delta-1}.$$

Consider the proprietary software vendor. Note that

$$\frac{\partial \pi_P^*}{\partial \delta} = \frac{(1-\alpha)(\delta-1+c_O)(1-\delta(2\delta-1)+(8\delta^2-4\delta-1)c_O)}{(\delta-1)^2(4\delta-1)^3}.$$

Since $\delta > 1$, $\delta-1+c_O > 0$. Thus, the sign of $\frac{\partial \pi_p^*}{\partial \delta}$ is determined by $1-\delta(2\delta-1)+(8\delta^2-4\delta-1)c_O$. Let

$f_2 = 8\delta^2 - 4\delta - 1$. Since $f_2(\delta = 1) = 3 > 0$ and $\left.\frac{\partial f_2}{\partial \delta}\right|_{\delta=1} = 12 > 0$, we have $f_2 > 0$. Therefore,

$$\frac{\partial \pi^*_P}{\partial \delta} > 0 \text{ when } c_O < \frac{1 - \delta(2\delta - 1)}{8\delta^2 - 4\delta - 1},$$
$$\frac{\partial \pi^*_P}{\partial \delta} < 0 \text{ when } c_O > \frac{1 - \delta(2\delta - 1)}{8\delta^2 - 4\delta - 1}.$$

QED.

Proof of Proposition 6

Note that

$$\frac{\partial p^*_O}{\partial \delta} = -\frac{3 + \alpha + 4\alpha\beta - 2(1-\alpha)c_o}{(7 + \alpha - 4\delta)^2} = -\frac{(\alpha + 4\alpha\beta + 2\alpha c_O + 1) + 2(1 - c_O)}{(7 + \alpha - 4\delta)^2}$$

Recall that $c_O < 1$. Thus, $\frac{\partial p^*_O}{\partial \delta} < 0$. Also note that

$$\frac{\partial p^*_P}{\partial \delta} = \frac{2\alpha^2\beta - 2\alpha(3 + \beta - 2\delta) + 4(7 - 2\delta)\delta + (1-\alpha)^2 c_O - 26}{(7 + \alpha - 4\delta)^2}$$
$$= -\frac{2\alpha\beta(1-\alpha) + 8\left(\delta - \frac{7}{4}\right)^2 + 4\alpha(1-\delta) + 2\alpha + (1 - (1-\alpha)^2 c_O) + \frac{1}{2}}{(7 + \alpha - 4\delta)^2}.$$

Since $0 < \delta < 1$, $0 \le \alpha \le 1$, and $c_O < 1$, the above expression is negative, i.e., $\frac{\partial p^*_P}{\partial \delta} < 0$. Therefore, both prices decrease with δ, implying that they increase with the level of quality difference. ***QED***.

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