2006

Optimal software design and pricing in the presence of open source software

Qian Tang
National University of Singapore, ctang@comp.nus.edu.sg

Jing Wu
National University of Singapore, wujing@comp.nus.edu.sg

OPTIMAL SOFTWARE DESIGN AND PRICING IN THE PRESENCE OF OPEN SOURCE SOFTWARE

[1]Qian Candy Tang, Dept. of Information Systems, National University of Singapore, Singapore 117543, ctang@comp.nus.edu.sg

Jing Wu, Dept. of Information Systems, National University of Singapore, Singapore 117543, wujing@comp.nus.edu.sg

Abstract

Open source software (OSS) has become an increasingly threatening competitor to traditional proprietary software. In this paper, we study the competition between proprietary and OSS by considering consumer's taste difference using a Hotelling model. In particular, we seek to answer how commercial software vendors should optimally set the price and design its product. Our analysis suggests that the optimal strategy of the commercial firm is dependent on consumer's fit cost and the positioning (design) of open source software. Specifically, we find that if the OSS is targeted to consumers with extreme requirements, the commercial firm should serve only a proportion of the entire population and the commercial firm's profit is maximized. Furthermore, our analysis shows that the social welfare is maximized when open source software targets more specialized users. Further, In the presence of positive network externalities, the commercial firm enjoys greater profit when there's positive network effect. However, the commercial firm's profit is not monotonically increasing or decreasing in network intensity.

Keywords: proprietary software, open source software, Hotelling model, network externality

[1] Authors are in alphabetical order

1 INTRODUCTION

Recent years have seen a rapid growth of open source software (OSS). OSS refer to those programs "whose licenses give users the freedom to run the program for any purpose, to study and modify the program, and to redistribute copies of either the original or the modified program without having to pay royalties to previous developers" (Wheeler, 03). Since the first open source software was developed by Richard Stallman (GNU) in the 70's, there have been a myriad of open source applications, ranging from common office suites such as StarOffice, to database (mySQL) and thousands of specialized scientific applications[1]. Open source software challenges the traditional idea that software must be licensed and can not be modified according to individual needs. It makes source code publicly available for free usage and modification, including bug fixing and customizing features. Ever since the burgeoning of open source software, it has attracted more and more attentions from individual users and organizations due to its "free of charge" and "freedom of distribution and modification." A recent survey by Netcraft (www.netcraft.com) suggests that the market share of Apache grows rapidly and has exceeded Microsoft's IIS.

The growing popularity of open source software has stimulated wide-spread interest in academia. Numerous studies have been dedicated to decode the myth of open source participation and the relationship between open source and closed source software. Lerner and Tirole (2002) suggest that developers contribute to open source projects because of immediate and delayed economic benefits (signalling incentives) from open source development. Based on a case study of (LA)TEX, Gaudel (2003) concludes that open source inspired commercial software more than the reverse. On the other hand, the software industry, which traditionally operates on basis of software licensing, is more concerned with how to respond strategically to the open source phenomenon. Microsoft, the once strongest opponent to open source movement, has recently decided to include open source code in its shipping of Windows Server 2003 Cluster Edition (Galli 2005). Sun Microsystems is actively involved in the development of open source based Java projects in a hope to promote Java-related products. Without a doubt, the profitability of a commercial firm is affected (if not threatened) when the consumers are offered with an alternative free option other than its proprietary software. Commercial firms are now confronted with the critical decision on how to optimally compete with open source software.

The objective of this paper is to answer the key question about how a profit-seeking software firm should compete with open source software. Although competition has been the classic research topic in economic literature, the competition between open source and proprietary software has the following distinct features that deserve further analysis: (1) traditional duopoly competition model studies the equilibrium of two profit-making firms while open source software is free of charge and can't be made

[1] For more details, please refer to Scientific Applications on Linux (SAL) (http://sal.linet.gr.jp/index.shtml)

for profit by itself; (2) traditional competition models normally study the optimal pricing while in case of software competition, the software producers has two arms to fight with competition – pricing and product design. For instance, if the commercial product is quite similar to open source products, the commercial firm faces fierce competition, but if the proprietary software is highly differentiated, the product might appeal to a small niche market only; (3) software products exhibit positive network externalities, which further complicates the decision of optimal price and product design.

In this study, we employ a stylized Hotelling model to study the optimal pricing and design of proprietary software in the presence of competitive open source software. We address the following research questions: (1) what is the impact of open source software's positioning (design) on the optimal price, design and profit of the proprietary software; (2) how is social welfare affected by the positioning of open source software; (3) what are the firm's optimal strategy and profit when there's positive network effect. Our analysis suggests that the profit of the commercial firm is dependent on fit cost and the positioning (design) of open source software. In particular, the commercial firm is best off when the open source software targets more specialized users. Furthermore, if the open source software targets the more specialized users, the commercial firm should serve only a proportion of the whole population. The market share of the commercial firm is largest when the open source software caters to users with extreme requirements, and a predatory pricing strategy is adopted by the commercial firm. In addition, we find that the social welfare is maximized when open source software targets more specialized users. Finally, a simple analysis of a special case suggests that the commercial firm gains more profit when there's positive network externalities. However, since both open source and proprietary software benefit from network externalities, the commercial firm's profit is not monotonically increasing or decreasing in network intensity.

The remainder of the paper is organized as follows. Section 2 gives a review of literature on open source software. We present the model and major findings in Section 3, followed by conclusions and discussions of future research direction in Section 4.

2 LITERATURE REVIEW

The open source phenomenon has captured attention by academic scholars in various areas. One stream of literature deals with the motivation of participating in open source projects. Lerner and Tirole (2002) explain the immediate and delayed benefit from engaging in open source development. They find that the developers improve programming ability and get recognition from peer developers. In the long run, they gain reputation and attain more desirable jobs. Bonaccorsi and Rossi (2003) find similar results with that of Lerner and Tirole (2002). Schmidt and Schnitzer (2002) divide programmers into different types: those who are devoted to bug fixing (sophisticated users), those who are devoted to software development (signaling incentives), and those who are employed by the commercial software companies. Lakhani and Wolf (2003) use a web-based survey and find that joy-based intrinsic motivations, namely how a person feels from a creative project, is the strongest and most pervasive driver. Roberts et al (2004) evaluate the theoretical model using survey from Apache web server projects. Their results reveal that the different types of motivations lead to different contributions to open source projects. The study of motivations of open source development helps to understand the distinctive characteristics of open source software. For example, it explains why open source software usually has an inferior graphical interface and documentation compared to its proprietary counterparts.

A second stream of research compares the quality of open source and proprietary software, which has led to contradictory views. Kuan (2001) and Johnson (2004) believe that open source software provides higher quality than closed source software. At the same time, many industrial experts have raised concerns with the quality of open source software, criticizing its lack of customer support, security and reliability of open source software (Shell 2005, Massel 2005). The different views imply that open source and proprietary software are adopted (preferred) by different groups of users. Bessen (2004) finds that the firms with strong software development capability or complex, specialized needs will most likely use open source software. Similarly, Gaudeul (2003) points out that because of lack of interface, open source software is left with users who cannot afford proprietary software (students), those who need its advanced capabilities (academics) and those who valued the flexibility to customize its own product (sophisticated users).

Our research is mostly related to a third stream of research that focuses on the competition between open source and commercial software. Casadesus-Masanell and Ghemawat (2003) examine the dynamic competition between commercial software and open source by analyzing the demand-side learning effect. They conclude that in equilibrium the open source software will either coexist with commercial software or be driven out of the market. Gaudeul (2004) explores the market equilibrium by considering the interaction between software users and developers. It is assumed that users have different valuations of software features and developers have heterogeneous programming costs. Gaudeul (2004) concludes that in equilibrium, open source software is either driven out of market by proprietary software or coexists with proprietary software. If open source software does survive, it is used either by users who like more advanced features and do not care about awkward user interfaces or those low-income consumers who cannot afford to buy the proprietary software. Our research differs from the work by Gaudeul (2004) in that we use horizontal differentiation model instead of the vertical differentiation adopted by Gaudeul (2004). In general, open source or proprietary software is preferred by different types of users: expert users like open source software because of its more advanced features and the flexibility to modify source code; while ordinary users prefer proprietary software since it offers better interface and more reliable customer support (Nichols & Twidale, 2003). In addition, we study the impact of open source software's positioning on the optimal design and pricing of proprietary software, while Gaudeul (2004) concentrates on characterizing the equilibrium market share of open source and proprietary software.

3 THE MODEL

Consider two differentiated but competitive software products in market. One is offered by a commercial firm at price P and the other is free as open source software (OSS). Although in many cases, a commercial firm can make profit by selling complementary applications or services to open source software, we focus on competition between a free open source and commercial software to study the optimal strategies of a commercial software firm in the presence of not-for-profit open source software. Software users, which differ in computing skills and knowledge, have different tastes of software products. Consumer tastes can be manifested in multiple ways. For example, expert users are more interested in advanced functions and the flexibility to customize source code while ordinary users are more interested in better interface for the ease of use. We model consumer's taste as her preference between open source proprietary software. We adopt a Hotelling model to represent consumer taste, denoted by x, which is distributed uniformly in the interval between 0 to 1. The proprietary software and open source software are situated at points a and $1-b$, respectively (see Figure 1). Without loss of generality, we assume that $(1-b) > 1/2$. The opposite scenario can be studied by simply reversing the analysis in this paper.

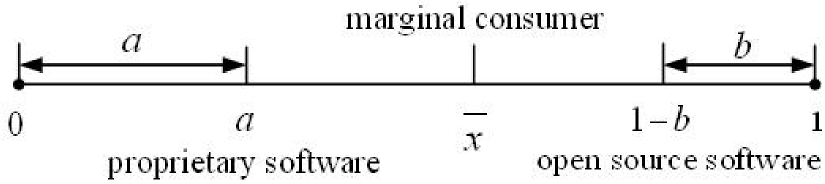

Figure 1. The Hotelling model

We assume that the location of OSS ($1-b$) is exogenously given. This is due to the idiosyncratic development process of open source projects. Open source software is developed by voluntary programmers. A new version of OSS is released whenever there's sufficient contribution by the development community. Unlike commercial firms which can set a long-term development objective, open source projects are less coordinated and organized. As a result, the design of open software is more random in nature compared to proprietary software. Therefore, we first explore commercial firm's optimal design and pricing strategies when the location (design) of OSS is given. Later, we compare the firm's profit and social welfare with respect to different settings of OSS location. In a one-shot model, we assume the location of the OSS remain fixed during the period of study. In addition, we assume consumers have perfect information about the location (design) of OSS and proprietary software. With the pervasive usage of Internet, users nowadays can easily find out information about a software product at low cost, such as via online forums and professional reviews.

Consumer's position on the Hotelling line represents her ideal location of software product. Each consumer incurs a fit cost that is proportional to the distance between her ideal product location and the location of proprietary or open source software. Let t be the unit fit cost and v be consumer's reservation price for each type of software. Then the net utility for a consumer located at point x from using open source (U_{os}) and proprietary software (U_{cs}), are defined in Eq. (1).

$$U_{os}(x) = v - t\left|1-b-x\right|; \qquad U_{cs}(x) = v - t\left|x-a\right| - P \tag{1}$$

Consumers choose OSS or proprietary software by comparing her net utility from each type of software. The marginal consumer, denoted by $\overline{x}$, is indifferent between open source and proprietary software. Since the consumers are uniformly distributed on the Hotelling line and the OSS is located at the right half of the line, the proprietary software must be located to the left of the OSS. Otherwise, the commercial firm will suffer from a smaller market share with the same price. As a result, the marginal consumer must be situated between the proprietary and OSS, see Fig. 1. Specifically, the marginal consumer is described in Eq. (2).

$$v - t(\overline{x} - a) - P = v - t(1 - b - \overline{x}) \tag{2}$$

The commercial firm should optimally set the price and location of its proprietary software to maximize its profit. In order to focus on the competition between OSS and proprietary software, we don't consider the case when the marginal consumer receives negative utility. In other words, we assume that no consumer between a and *1* is "stranded" by both types of software. Therefore, the commercial firm has two options – cover the entire market demand together with OSS; or cover a proportion of market demand together with OSS. In the following subsections, we analyze commercial firm's optimal profit for each option. The optimal strategy is found by selecting the strategy that maximizes the firm's profit. Due to limitation of space, we don't provide detailed derivations. All proofs are available upon request.

3.1 Market is fully covered

When the market is fully covered, all consumers derive non-negative utilities from either type of software. It is required that the net utilities for consumers with largest fit cost, i.e., the consumer who are situated at point 0 and the marginal consumer situated at point $\overline{x}$, are non-negative. When the market is fully covered, all consumers to the left of the marginal consumer will purchase the proprietary software and consumers to the right of the marginal consumer will use OSS. The market share for the commercial firm is $\overline{x}$, which is described in Eq. (3). In sum, the profit maximization problem for the commercial firm is formulated as Eq. (3) below. We solve for the constrained optimization problem by using Kuhn-Tucker conditions. The optimal price, location and profit of the commercial firm are summarized in Lemma 1.

$$\begin{aligned} &\underset{P,a}{Max} \quad \pi = \overline{x}P = \frac{t(1-b+a)-P}{2t}P \\ &s.t. \quad U_{cs}(0) = v - ta - P \geq 0 \\ &\qquad\; U_{cs}(\overline{x}) = v - t\left(\frac{t(1-b+a)-P}{2t} - a\right) - P \geq 0 \end{aligned} \tag{3}$$

Lemma 1. If $\frac{1}{2} < (1-b) < 2\frac{v}{t}$, the market is fully covered by the OSS and proprietary software, and

a) If $\frac{1}{2} < 1 - b < \frac{5v}{3t}$, the optimal price is $P_1^* = \frac{t(1-b)+v}{4}$; the optimal location is $a_1^* = \frac{3v - t(1-b)}{4t}$; the commercial firm's profit is $\pi_1^* = \frac{[t(1-b)+v]^2}{16t}$;

b) If $\frac{5v}{3t} < 1-b < 2\frac{v}{t}$, the optimal price is $P_2^* = \frac{3v - t(1-b)}{2}$; the optimal location is $a_2^* = \frac{1}{2}(1-b-\frac{v}{t})$; the commercial firm's profit is $\pi_2^* = (1-b-\frac{v}{t})(\frac{3v-t(1-b)}{2})$.

3.2 Market is not fully covered

When the market is not fully covered, some consumers located in the far left section of the Hotelling line derive negative utility from both OSS and proprietary software and are thus left out of market. In such case, the furthest consumer who can be served by the proprietary software is the consumer who derives zero utility. The left most customer who will buy proprietary software (x_0) is defined by Eq. (4)

$$U_{cs}(x_0) = v - t(a - x_0) - P = 0 \tag{4}$$

In correspondence, the demand (market share) of the proprietary software is $\overline{x} - x_0$. We formulate the profit maximization decision of the commercial firm in Eq. (5). The constrained optimization problem can be solved by using Kuhn-Tucker conditions. The optimal price, location and profit of the proprietary software is given in Lemma 2.

$$\begin{aligned} \underset{P,a}{Max} \quad & \pi = (\overline{x} - x_0)P = \frac{t(1-b-a) - 3P}{2t} P \\ s.t. \quad & U_{cs}(0) = v - ta - P < 0 \\ & U_{cs}(\overline{x}) = v - t(\frac{t(1-b+a) - P}{2t} - a) - P \geq 0 \end{aligned} \tag{5}$$

Lemma 2. If $2\frac{v}{t} < (1-b) < 1$, the market is not fully covered by OSS and proprietary software. The optimal price is $P_3^* = \frac{v}{2}$; the optimal location is $a_3^* = 1 - b - \frac{3v}{2t}$; the profit is $\pi_3^* = \frac{v^2}{2t}$.

3.3 Analysis of results

The optimal strategies prescribed by Lemma 1 and Lemma 2 are dependent on the ratio of product valuation and fit cost (v/t) as well as the location of the OSS ($1-b$). For example, when $v/t > 1/2$, the condition in Lemma 2 is never satisfied since $1-b < 1$. Proposition 1 summarizes the optimal strategies of the commercial firm under different conditions. Proposition 2 shows the optimal strategies with respect to different design of the open source software.

Proposition 1. The optimal price, location and profit of the commercial firm given fit cost (t), product valuation (v) and the location of the OSS ($1-b$) is as follows, where P_i^*, a_i^* and π_i^* (*i=1, 2, 3*) are defined in Lemma 1 and 2.

(1) If $0 < v/t < 3/10$, the optimal strategy is to cover entire market by setting the price at P_2^* and locate at a_2^* when $\frac{5v}{3t} < 1-b < 2\frac{v}{t}$, while the optimal strategy is to cover partial market by setting the price at P_3^* and locate at a_3^* when $2\frac{v}{t} < 1-b < 1$;

(2) If $3/10 \le v/t < 1/2$, the optimal strategy is to cover entire market by setting the price at P_1^* and located at a_1^* when $\frac{1}{2} < 1-b < \frac{5v}{3t}$ and set the price the price at P_2^* and locate at a_2^* when $\frac{5v}{3t} < 1-b < 2\frac{v}{t}$, while the optimal strategy is to cover partial market by setting the price at P_3^* and locate at a_3^* when $2\frac{v}{t} < 1-b < 1$;

(3) If $1/2 \le v/t < 3/5$, the optimal strategy is to cover entire market by setting the price at P_1^* and located at a_1^* when $\frac{1}{2} < 1-b < \frac{5v}{3t}$ and set the price the price at P_2^* and locate at a_2^* when $\frac{5v}{3t} < 1-b < 2\frac{v}{t}$;

(4) If $v/t \ge 3/5$, the optimal strategy is to cover the entire market by setting the price at at P_1^* and located at a_1^*.

Proposition 2. The commercial firm's profit is at maximum when OSS targets more specialized users ($2v/t < 1-b < 1$), i.e. $\pi_3^* > \pi_2^* > \pi_1^*$. In addition, the commercial firm's market share is maximized when $2v/t < 1-b < 1$, i.e., $\overline{x}_3^* - x_0 > \overline{x}_2^* > \overline{x}_1^*$. The price of the proprietary software is lower when the market is not fully covered, i.e., $P_1^* > P_3^*, P_2^* > P_3^*$.

Next we examine the impact of OSS positioning of on social welfare. Since the price transferred from consumers to the commercial firms cancel out when we calculate social welfare, we only need to examine the total fit cost and gross utility by the consumers. The total fit cost (TF) is defined in Eq (6), where the lower bound of integration of the first term (L) is *0* if market is fully covered and x_0 if market is not fully covered. Total social welfare is calculated as $v(1-L)-TF$.

$$TF = \int_{L}^{a} t(a-x)dx + \int_{a}^{\bar{x}} t(x-a)dx + \int_{\bar{x}}^{1-b} t(1-b-x)dx + \int_{1-b}^{1} t(x-(1-b))dx \qquad (6)$$

Proposition 3. The social welfare is maximized when OSS targets more specialized users. Specifically, social welfare is at maximum when $(1-b)=2v/t$.

Proposition 1 suggests that the commercial firm is best off when the OSS caters to users with extreme requirements. In addition, we find that commercial firm does not need to serve the entire market if the OSS is situated at extreme locations. Interestingly, although the commercial firm only targets partial consumers, its market share is still larger than the case when the market is fully covered. When the market is not fully covered, the commercial firm will set a low predatory price to command a large market share and subsequently gain greater profit. Proposition 2 suggests that the profit maximization objective by the commercial firm is also aligned with the objective of a social planner. Currently, most open source products are adopted by the niche market of low-income or high-skill users. Advocators of open source software often argue that the open source community has been improving the interface and documentation to make it more like their user-friendly proprietary counterparts. However, our analysis suggests that the social walfare might decrease with improved usability of open source products, as it reduces the differentiation between OSS and proprietary software. At the same time, commercial firm suffers from profit loss by the presence of a “closer-look” open source product.

3.4 The impact of network effect

In this section, we examine the impact of network effect on commercial firm’s optimal strategy and profit. The competition between OSS and proprietary software becomes rather complicated in the presence of positive network externalities. For example, the marginal consumer is found between OSS and proprietary software without network effect. However, in the presence of positive network effect, the marginal consumer could be situated to the left of the proprietary software if the intensity of network externalities for OSS is sufficiently large. It’s beyond the space limit to examine all possible scenarios. Rather, we present the simplest case. That is, we assume that the network intensity is same for both OSS and proprietary software. Further, we study the special case where the fit cost is low ($t<v$) and the OSS is situated at the extreme location ($b=0$). Notice that optimal strategy without network effect when $t<v$ is specified by case (4) in Proposition 1, i.e., the market is fully covered. In comparison, we analyze the commercial firm’s profit in the presence of network externalities by considering the case when the market is fully covered.

Let γ be the intensity of network effect for both OSS and proprietary software. Further, it is assumed that there’s no cross-product externality between OSS and proprietary software. This is because open source and proprietary software are normally adopted by separate consumer camps with different tastes. When there's positive network externality, each consumer enjoys an increase of utility, characterized by γQ_i, where Q_i ($i = c, o$) is the total installed base of the software adopted by the particular consumer.

The net utilities from open source ($U_{os}^{'}$) and closed source ($U_{cs}^{'}$) software with network externality for a consumer of type x is defined by Eq. (7).

$$U_{os}^{'}(x) = v - t(1-x) + \gamma Q_o \quad ; \qquad U_{cs}^{'}(x) = v - t(x-a) - p + \gamma Q_c \tag{7}$$

Let $\overline{x}^{'}$ be the marginal consumer indifferent between OSS and proprietary software. If the market is fully covered, the size of the installed base for OSS is $Q_o = 1 - \overline{x}^{'}$ and the size of the installed base for proprietary software is $Q_c = \overline{x}^{'}$. We assume that $\gamma < t$, which is required by the decrease of demand in price. The profit maximization problem for the commercial firm is expressed as follows.

$$\underset{p,a}{Max} \quad \pi = Q_c P = \frac{p + \gamma - t - ta}{2(\gamma - t)} P \tag{8}$$

s.t.

$$\gamma + at - t \le P \tag{8a}$$

$$P \le t - \gamma + 2a\gamma - at \tag{8b}$$

$$v - t(\overline{x}^{'} - a) - P + \gamma \overline{x}^{'} \ge 0 \tag{8c}$$

$$v - ta - P + \gamma \overline{x}^{'} \ge 0 \tag{8d}$$

Conditions (8a) and (8b) specify that the marginal consumer is situated between proprietary (located at *a*) and open source software (located at *1*). Conditions (8c) and (8d) are required to ensure that market is fully covered, i.e., the net utilities for consumer at location *0* and $\overline{x}^{'}$ are non-negative. We apply Kuhn-Tucker conditions to solve the above constrained optimization problem. The solution is presented in Proposition 4. The impact of network externality is summarized in Proposition 5.

Proposition 4. In the presence of network externality, the optimal price, location and profit of the proprietary software when $t < v$, $b = 0$ are specified as follows.

(1) If $0 < \gamma < 2/3t$, the optimal price is $P_1^{'*} = \frac{1}{2}(t - \gamma)$, the optimal location is $a_1^{'*} = \frac{1}{2}$ and the commercial firm's profit is $\pi_1^{'*} = \frac{1}{8}(2t - \gamma)$;

(2) If $\frac{2}{3}t < \gamma < t$, the optimal price is $P_2^{'*} = \frac{\gamma(\gamma - t)}{\gamma - 2t}$, the optimal location is $a_2^{'*} = \frac{2(\gamma - t)}{\gamma - 2t}$ and the commercial firm's profit is $\pi_2^{'*} = \frac{\gamma(\gamma - t)}{\gamma - 2t}$.

Proposition 5. In the presence of network externality, the price of commercial software decreases, the market share of the proprietary software increases, and the commercial firm's profit increases. However, the commercial firm's profit is not monotonically increasing or decreasing in network externality intensity. Specifically, $P_1^* > P_1^{'*} > P_2^{'*}$, $Q_1^* < Q_1^{'*} < Q_2^{'*}$ and $\pi_1^{'*} > \pi_2^{'*} > \pi_1^*$.

In summary, we find the commercial firm benefits from positive network externality. More interestingly, we find that the commercial firm's profit is not strictly increasing or decreasing with network intensity. This is because both open source and proprietary users benefit from the positive network effect. In other words, larger network intensity renders both types of software more attractive to users.

Conclusion

Open source software has been gaining popularity among individuals and organizations as a "free " alternative to traditional proprietary software. No doubt, the commrecial firm's profit is affected by the presence of open source software. Past study on the comparison between open source and proprietary software suggests that open source software offers better functionality while proprietary software has advantage in ease of use and reliable customer support. Consequently, open source and proprietary software are normally preferred by different groups of consumers with distinct requirement (tastes). In this paper, we employ a Hotelling model to study the optimal strategies of commercial firms when consumers have different tastes. In particular, we seek to solve for the optimal design and pricing of proprietary software. Further, we analyze the impact of network externaltiy on the optimal strategy and profit of the commercial firm.

Our analysis suggests that the profit of the commercial firm is dependent on the fit cost and the positioning of open source software. The profit of the commercial firm is maximized when the open source software targets more specialized users. Furthermore, the market share of the commercial firm is largest when the open source software caters to users with extreme requirements, and the commercial firm should set a low price to capture a proportion of the market. In addition, we find that the social welfare is maximized when open source software targets more specialized users. Finally, our analysis suggests that the commercial firm gains more profit when there's positive network externalities.

Our research can be extended in the following directions. First, we shall analyze whether the commercial firm should reach out to attract open source users to compete. That is, whether all customers located between open source and proprietary software should be served. Secondly, we shall explore the possibility of different network intensity for open source and proprietary software. Finally, we shall provide answers to optimal strategies for the more complicate situation when the fit cost is high ($t > v$).

References

Bessen, J. (2004) Open Source Software: Free Provision of Complex Public Goods. Working paper.

Bonaccorsi A. and Rossi C., 2003, "Why Open Source Software Can Succeed", Research Policy, 32, 1243-1258.

Casadesus-Masanell and Ghemawat, 2003, "Dynamic Mixed Duopoly: A Model Motivated by Linux vs. Windows" Working Paper, Graduate School of Business Administration, Harvard University.

Galli, P (2005), Open Source Code finds Way into Microsoft Prduct. eWeek.com article, Sep 15, 2005.

Gaudeul, A. (2004). The (LA)TEX project: A case study of open source software. Research paper, Universities of Toulouse and Southampton.

Gaudeul A., 2004, "Competition between Open-Source and Proprietary Software: The (LA)TEX case Study", Unpublished working paper, Universities of Toulouse and Southampton.

Roberts J., Hann I., and Slaughter S., 2004, "Understanding the Motivations, Participation and Performance of Open Source Software Developers: A Longitudinal Study of the Apache Projects", Unpublished working paper, Carnegie-Mellon University.

Johnson J. P., 2004, "Collaboration, Peer Review and Open Source Software", Unpublished working paper, Cornell University.

Kuan J., 2001, "Open Source Software as Consumer Integration into Production", Unpublished working paper, Stanford University.

Lakhani R. K. and Wolf G. R., 2003, "Why Hackers Do What They Do: Understanding Motivation and Effort in Free/Open Source Software Projects", Working Paper 4425-03, MIT Sloan School of Management.

Lerner J. and Tirole J., 2002, "Some Simple Economics of Open Source", *Journal of Industrial Economics*, 52(2), 197-234.

Massel, D. (2005). The changing face of open source. LinuxInsider.com article. Oct 21, 2005.

Nichols M. D. and Twidale M. B., 2003, "Usability and Open source Software", *First Monday*, 8(1)

Schmidt K. and Schnitzer M., 2002, "Public Subsidies for Open Source? Some Economic Policy Issues of the Software Market", CEPR Discussion Paper.

Shell, S. (2005). Open source vs. commercial software: why proprietary software is here to stay. Informit.com article, Oct. 14, 2005.

Wheeler, D. A (2003). Why open source software/free software (OSS/FS)? Look at the number! (http://www.dwheeler.com/oss_fs_why.html), December 31, 2003.