Competition between Free Open Source, Commercial Open Source and Proprietary Software

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***Abstract*—**This paper investigates competition between open source and proprietary software. Open source software is divided into two types: free open source and commercial open source. Free open source software can be available from the not-for-profit community, and Commercial open source software is software product based on free open source software. The usability of both free and commercial open source software is assumed to be inferior to proprietary software. It finds that: (i) when commercial open source vendor faces competition from proprietary software and free open source software, it may still be able to obtain profits; (ii) commercial open source vendor's pricing (resp. share or profit) may still be much lower (resp. less) than that of proprietary vendor even if its software functionality is not inferior to proprietary software; (iii) commercial open source vendor's pricing and profit may not increase as its software usability increases; (iv) proprietary software's price decreases with the usability of commercial open source software.

***Index Terms*—**proprietary software, open source software, price competition, software features, software usability

I. Introduction

Nearly two decades, the rapid development of open source is a significant phenomenon in software industries. Open source software (OSS) is a sort of software whose sources codes are allowed software developers to share, to identify and correct errors, and redistribute [1]. The total of work invested into open source software projects is growing at an exponential rate and can be expected to continue growing at this rate for a while before slowing down [2]. In this background, more and more companies (e.g., Red Hat Inc) build commercial products based on open source software. Reference [3] called privately developed software based on publicly available source codes commercial open source software. Examples are Redhat Linux, MySQL, SugarCRM, Jaspersoft, and Alfresco. Some scholars make a fundamental distinction between commercial and community open source [4]. Community open source is open source software that is owned by a community, whose members don't derive direct revenues from the software. In contrast, commercial open source is open source software that is owned by a legal entity with the purpose of deriving revenues from the software.

Reference [5] divided software quality into two components: usability (includes ease of installation, documentation, user interface and level of technical support) and features (includes feature set, reliability, security etc). Commercial open source vendor improves the features or usability of the existing community open source software and generates a product that contains both publicly and privately developed components. By expanding the vertical differentiation model [6], this study analyzes competition between open source and proprietary software in a market when commercial open source software appears. We compare equilibrium price, share and profit for different types of software vendor, and then analyze the impact of commercial open source software's usability on equilibrium price for both commercial open source and proprietary vendors.

With its rapid proliferation, open source software is now competing with proprietary software in many segments markets. There have been some studies investigate competition between open source and proprietary software. For examples, Reference [7] examined the quality debate under closed and open source environments in monopoly and competitive markets. It showed that no dominant quality advantage of one method over another under two circumstances and both open source and closed source software's qualities decreased in a competitive market. Moreover, it gave conditions under which each method can generate higher quality software; Reference [5] analyzed the impact of competition from open source software on proprietary software producers. It argued that competition from open source software can induce proprietary software producer to increase its software quality and price relative to those of the monopolist, and can lead to a reduction in social welfare; Reference [8] studied how users' skills and network effects affect the market where open source software competes with proprietary software. It assumed users make adoption decisions only considering their own skills and network effects of the software, and then found that the proprietary software dominates the market when the open source software does not provide higher benefits to users; Reference [9] assumed perfect software compatibility, a network externality component of software quality, and accumulation of experience in software use and implementation. In comparison to the

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monopolistic case, it found that, in a duopoly created by the emergence of an open source program, the proprietary software provider will reduce its selling price if its network of users is larger than the open source network and its users are largely familiar with its program, or it has a small network of unskilled users; References [10], [11] and [12] investigated the differentiation, compatible strategies and quantity competition between open source and proprietary software and found that: (i) the software differentiation and quantity strategies depend on the learning costs of open source software; (ii) the compatible strategies are affected by the user's expectations and market coverage; Reference [13] analyzed how open source software affects the quality of proprietary software and found that the quality of proprietary software may not increase in the quality of open source software.

All of above papers only consider the free (or community) open source software and don't involve commercial open source software. The following two papers are exceptions. Reference [14] compared innovation incentives for commercial open source producers under the GNU General Public License and Berkeley Software Distribution License (i.e., GPL and BSD). It found that the incentive towards software features (resp. usability) innovation is always higher (resp. lower) under BSD than under GPL. Reference [15] examined R&D competition for commercial open source providers under the GNU General Public License and found that: (i) although the GPL requires providers open the software codes, they may still have incentives to invest in software features under private optimum; (ii) the provider with high software usability has much higher incentive to invest in software features than the one with low usability does; (iii) from a public policy perspective, providers invest too little in software features under GPL. The above two papers study innovation incentives for commercial open source vendors, but both them don't consider competition between commercial open source and proprietary software producers.

The rest of the paper is organized as follows. Section 2 presents the basic model. Section 3 solves the equilibrium solutions. Section 4 conducts comparative static analysis. Final part concludes the paper.

II. The Basic Setup

There exist three types of software in a market, one of which is from the not-for-profit open source community (called FOSS in this paper), another is from the proprietary producer (called PS in this paper) and the other is from the commercial open source producer (called COSS in this paper). Producers can derive the software codes from open source community freely, but they must comply with relevant open source licenses. The GNU General Public License (GPL) is the most common open source license, which requires producers open software codes of their development. This paper only investigates the case that producers build commercial open source software based on free open source software from community under the GPL.

Software users are indexed by their level of technical ability, measured by parameter θ, uniformly distributed with density 1 over interval $[0,1]$ as in Fig. 1. Assume that users with higher level of technical skills have lower θ, while those with lower degree of technical capability have higher θ. Moreover, a user with lower technical expertise has higher willingness to pay for software usability than a user with higher technical expertise [5], [8], [16].

Figure 1. The generic user's technical ability and the market.

The indirect utility functions for the generic consumer at $\theta \in [0,1]$ when he/she uses FOSS, COSS and PS are respectively given by

$$u_o = \theta v_o + f_o - p_o \tag{1}$$

$$u_1 = \theta v_1 + f_1 - p_1 \tag{2}$$

$$u_2 = \theta v_2 + f_2 - p_2 \tag{3}$$

where v_o, v_1 and v_2 denote the usability levels of FOSS, COSS and PS respectively, and satisfy $0 < v_o < v_1 < v_2$, i.e., the usability of free (resp. commercial) open source software is assumed to be inferior to commercial open source (resp. proprietary) software; f_o, f_1 and f_2 (resp. p_o, p_1 and p_2) are the features levels (resp. prices) of FOSS, COSS and PS respectively. Note that: (i) free open source software can be freely available from open source community, so $p_o = 0$; (ii) because the GPL requires producers open software codes of their developments, this study assumes open source community and commercial open source producer can wholly obtain each others' features developments (i.e., $f_1 = f_o$).

The marginal consumer who is indifferent between using FOSS and COSS, indexed by $\hat{\theta}_{o1}$, is given by $u_o = u_1$:

$$\hat{\theta}_{o1} v_o + f_o = \hat{\theta}_{o1} v_1 + f_1 - p_1 \tag{4}$$

Solving (4), we obtain

$$\hat{\theta}_{o1} = \frac{p_1}{v_1 - v_o} \tag{5}$$

The marginal consumer who is indifferent between using COSS and PS, indexed by $\hat{\theta}_{12}$, is given by $u_1 = u_2$:

$$\hat{\theta}_{12} v_1 + f_1 - p_1 = \hat{\theta}_{12} v_2 + f_2 - p_2 \tag{6}$$

Solving (6), we obtain

$$\hat{\theta}_{12} = \frac{f_o - f_2 + p_2 - p_1}{v_2 - v_1} \tag{7}$$

To simplify the analysis, this paper assumes that: (i) $\hat{\theta}_{o1}$ and $\hat{\theta}_{12}$ satisfy $0 < \hat{\theta}_{o1} < \hat{\theta}_{12} < 1$; (ii) what software to use depends on user's software technical skills as in Fig. 2. When a user's technical skills meet $0 \le \theta < \hat{\theta}_{o1}$, he/she uses free open source software. When a user's technical skills meet $\hat{\theta}_{o1} \le \theta < \hat{\theta}_{12}$, he/she uses commercial open source software. When a user's technical skills meet $\hat{\theta}_{12} \le \theta < 1$, he/she uses proprietary software.

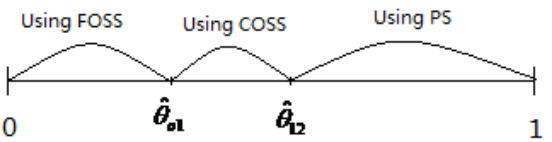

Figure 2. Users' decisions to use the software.

Therefore, the demand functions for the open source community, COSS provider and PS provider are respectively given by

$$d_o = \hat{\theta}_{o1} - 0 = \frac{p_1}{v_1 - v_o} \tag{8}$$

$$d_1 = \hat{\theta}_{12} - \hat{\theta}_{o1} = \frac{f_o - f_2 + p_2 - p_1}{v_2 - v_1} - \frac{p_1}{v_1 - v_o} \tag{9}$$

$$d_2 = 1 - \hat{\theta}_{12} = 1 - \frac{f_o - f_2 + p_2 - p_1}{v_2 - v_1} \tag{10}$$

The profit functions for COSS and PS providers are respectively given by

$$\pi_1 = p_1 d_1 = p_1\left(\frac{f_o - f_2 + p_2 - p_1}{v_2 - v_1} - \frac{p_1}{v_1 - v_o}\right) \tag{11}$$

$$\pi_2 = p_2 d_2 = p_2\left(1 - \frac{f_o - f_2 + p_2 - p_1}{v_2 - v_1}\right) \tag{12}$$

Note that the marginal costs for both commercial open source and proprietary software are assumed to equal zero.

III. The Optimal Solutions

The first-order conditions of (11) and (12) with respect to p_1 and p_2 are respectively given by

$$\frac{\partial \pi_1}{\partial p_1} = \frac{f_o - f_2 + p_2 - 2p_1}{v_2 - v_1} - \frac{2p_1}{v_1 - v_o} = 0 \tag{13}$$

$$\frac{\partial \pi_2}{\partial p_2} = 1 - \frac{f_o - f_2 + 2p_2 - p_1}{v_2 - v_1} = 0 \tag{14}$$

Solving (13) and (14), we obtain the equilibrium prices for COSS and PS

$$p_1^* = \frac{(v_1 - v_o)[(v_2 - v_1) + f_o - f_2]}{4(v_2 - v_o) - (v_1 - v_o)} \tag{15}$$

$$p_2^* = \frac{\begin{pmatrix} 2(v_2 - v_o)(v_2 - v_1) - [2(v_2 - v_0) \\ -(v_1 - v_o)](f_o - f_2) \end{pmatrix}}{4(v_2 - v_o) - (v_1 - v_o)} \tag{16}$$

Substituting (15) and (16) in (8), (9), (10), (11) and (12), we derive the following equilibrium outcomes

$$d_o^* = \frac{v_{21} + \Delta f}{4v_{2o} - v_{1o}} \tag{17}$$

$$d_1^* = \frac{v_{2o}(v_{21} + \Delta f)}{v_{21}(4v_{2o} - v_{1o})} \tag{18}$$

$$d_2^* = \frac{2v_{2o}v_{21} - (2v_{2o} - v_{1o})\Delta f}{v_{21}(4v_{2o} - v_{1o})} \tag{19}$$

$$\pi_1^* = \frac{v_{1o}v_{2o}(v_{21} + \Delta f)^2}{v_{21}(4v_{2o} - v_{1o})^2} \tag{20}$$

$$\pi_2^* = \frac{[2v_{2o}v_{21} - (2v_{2o} - v_{1o})\Delta f]^2}{v_{21}(4v_{2o} - v_{1o})^2} \tag{21}$$

where $\Delta f = f_o - f_2$, $v_{1o} = v_1 - v_o$, $v_{2o} = v_2 - v_o$ and $v_{21} = v_2 - v_1$.

According to (20), we know that, although commercial open source producers face competition from proprietary software with high usability and free open source software, they may still be able to obtain profits. A famous example is Red Hat, who uses open-source Linux to obtain huge profits. This may explain why more and more commercial open source vendors appear in some software markets.

Comparing equilibrium results for commercial open source and proprietary providers, we obtain the following conclusions.

Proposition 1.

(i) when $\Delta f < \frac{v_{21}(2v_{2o} - v_{1o})}{2v_{2o}}$, $p_2^* > p_1^*$; when $\Delta f > \frac{v_{21}(2v_{2o} - v_{1o})}{2v_{2o}}$, $p_2^* < p_1^*$;

(ii) when $\Delta f < \frac{v_{21}v_{2o}}{3v_{2o} - v_{1o}}$, $d_2^* > d_1^*$; when $\Delta f > \frac{v_{21}v_{2o}}{3v_{2o} - v_{1o}}$, $d_2^* < d_1^*$;

(iii) when $\Delta f < \frac{v_{21}\sqrt{v_{2o}}(2\sqrt{v_{2o}} - \sqrt{v_{1o}})}{\sqrt{v_{21}v_{2o}} + (2v_{2o} - v_{1o})}$, $\pi_2^* > \pi_1^*$; when $\Delta f > \frac{v_{21}\sqrt{v_{2o}}(2\sqrt{v_{2o}} - \sqrt{v_{1o}})}{\sqrt{v_{21}v_{2o}} + (2v_{2o} - v_{1o})}$, $\pi_2^* < \pi_1^*$.

Proof.

(i) because $p_2^* - p_1^* = \dfrac{v_{21}(2v_{2o} - v_{1o}) - 2v_{2o}\Delta f}{4v_{2o} - v_{1o}}$,

$p_2^* > p_1^*$ when $\Delta f < \dfrac{v_{21}(2v_{2o} - v_{1o})}{2v_{2o}}$ and

$p_2^* < p_1^*$ when $\Delta f > \dfrac{v_{21}(2v_{2o} - v_{1o})}{2v_{2o}}$;

(ii) because $d_2^* - d_1^* = \dfrac{v_{2o}v_{21} - (3v_{2o} - v_{1o})\Delta f}{v_{21}(4v_{2o} - v_{1o})}$,

$d_2^* > d_1^*$ when $\Delta f < \dfrac{v_{21}v_{2o}}{3v_{2o} - v_{1o}}$ and $d_2^* < d_1^*$

when $\Delta f > \dfrac{v_{21}v_{2o}}{3v_{2o} - v_{1o}}$;

(iii) $\sqrt{v_{1o}v_{2o}}(v_{21} + \Delta f) > 0$ because of $d_1^* > 0$ and $2v_{2o}v_{21} - (2v_{2o} - v_{1o})\Delta f > 0$ because of $d_2^* > 0$.

So $$\pi_2^* - \pi_1^* = \frac{\left\{\begin{array}{l} v_{21}\sqrt{v_{2o}}(2\sqrt{v_{2o}} - \sqrt{v_{1o}}) \\ -[\sqrt{v_{1o}v_{2o}} + (2v_{2o} - v_{1o})]\Delta f \end{array}\right\}}{v_{21}(4v_{2o} - v_{1o})^2} \times \left\{\begin{array}{l} [2v_{2o}v_{21} - (2v_{2o} - v_{1o})\Delta f] \\ +\sqrt{v_{1o}v_{2o}}(v_{21} + \Delta f) \end{array}\right\} > 0$$

when $\Delta f < \dfrac{v_{21}\sqrt{v_{2o}}(2\sqrt{v_{2o}} - \sqrt{v_{1o}})}{\sqrt{v_{21}v_{2o}} + (2v_{2o} - v_{1o})}$ and

$\pi_2^* - \pi_1^* < 0$ when $\Delta f > \dfrac{v_{21}\sqrt{v_{2o}}(2\sqrt{v_{2o}} - \sqrt{v_{1o}})}{\sqrt{v_{21}v_{2o}} + (2v_{2o} - v_{1o})}$.

Proposition 1 demonstrates that whether equilibrium pricing (resp. share or profit) of proprietary provider is higher (resp. more) than that of commercial open source provider depends on the difference in the level of their software features. $p_2^* > p_1^*$, $d_2^* > d_1^*$ and $\pi_2^* > \pi_1^*$ when $0 < \Delta f < \min\left\{\dfrac{v_{21}(2v_{2o} - v_{1o})}{2v_{2o}}, \dfrac{v_{21}v_{2o}}{3v_{2o} - v_{1o}}, \dfrac{v_{21}\sqrt{v_{2o}}(2\sqrt{v_{2o}} - \sqrt{v_{1o}})}{\sqrt{v_{21}v_{2o}} + (2v_{2o} - v_{1o})}\right\}$. This implies that, even if commercial open source provider's software features level is slightly higher than that of proprietary provider, its equilibrium pricing (resp. share or profit) may still be lower (resp. less) than that of proprietary software provider. This may be because the usability of commercial open source software is less than that of proprietary software [17]. However, the opposite situation may also occur when the features level of commercial open source software is much better than that of proprietary software (e.g., when $\Delta f > \max\left\{\dfrac{v_{21}(2v_{2o} - v_{1o})}{2v_{2o}}, \dfrac{v_{21}v_{2o}}{3v_{2o} - v_{1o}}, \dfrac{v_{21}\sqrt{v_{2o}}(2\sqrt{v_{2o}} - \sqrt{v_{1o}})}{\sqrt{v_{21}v_{2o}} + (2v_{2o} - v_{1o})}\right\}$).

Corollary 1. when $\Delta f \le 0$, $p_2^* > p_1^*$, $d_2^* > d_1^*$ and $\pi_2^* > \pi_1^*$.

Proof.

$\Delta f < \min\left\{\dfrac{v_{21}(2v_{2o} - v_{1o})}{2v_{2o}}, \dfrac{v_{21}v_{2o}}{3v_{2o} - v_{1o}}, \dfrac{v_{21}\sqrt{v_{2o}}(2\sqrt{v_{2o}} - \sqrt{v_{1o}})}{\sqrt{v_{21}v_{2o}} + (2v_{2o} - v_{1o})}\right\}$

when $\Delta f \le 0$. According to Proposition 1, $p_2^* > p_1^*$, $d_2^* > d_1^*$ and $\pi_2^* > \pi_1^*$.

When the features level of commercial open source software is not better than that of proprietary software, the equilibrium pricing (resp. share or profit) of proprietary provider is higher (resp. more) than that of commercial open source provider. As a numerical example, when $\Delta f = 0$, $v_1 = 1.5v_o$ and $v_2 = 2v_o$, there are $p_2^* = 4p_1^*$, $d_2^* = 2d_1^*$ and $\pi_2^* = 8\pi_1^*$. This may explain, in the desktop operating system market, despite the Red Hat's Linux in terms of functionality isn't inferior to Microsoft's Windows, the disadvantage of software usability leads its price (resp. share or profitability) to be much lower (resp. less) than that of Microsoft.

IV. Comparative Static Analysis

This part mainly analyzes how the usability of commercial open source software affects the equilibrium outcomes. To simplify the proofs, we set $v_o = 1$, $v_2 = 2$ and $v_1 \in (1, 2)$ here. To make sure $p_1^* \ge 0$ and $p_2^* \ge 0$, Δf is assumed to meet $-(2 - v_1) \le \Delta f \le \dfrac{2(2 - v_1)}{3 - v_1}$.

Proposition 2.

(i) when $-(2 - v_1) < \Delta f < \min\left\{\dfrac{3}{4}, \dfrac{2(2 - v_1)}{3 - v_1}\right\}$, p_1^* increases in v_1 if $v_1 \in (1, 5 - 2\sqrt{3 - \Delta f}]$ and decreases in v_1 if $v_1 \in (5 - 2\sqrt{3 - \Delta f}, 2)$; when $\dfrac{3}{4} \le \Delta f \le \dfrac{2(2 - v_1)}{3 - v_1}$, p_1^* increases in v_1;

(ii) p_2^* decreases in v_1.

Proof.

(i) when $v_o = 1$ and $v_2 = 2$, $p_1^* = \dfrac{(v_1 - 1)[(2 - v_1) + \Delta f]}{5 - v_1}$ and $\dfrac{\partial p_1^*}{\partial v_1} = \dfrac{v_1^2 - 10v_1 + 13 + 4\Delta f}{(5 - v_1)^2}$. When $v_1 \in (1, 2)$ and $-(2 - v_1) \le \Delta f \le \dfrac{2(2 - v_1)}{3 - v_1}$, $v_1^* = 5 - 2\sqrt{3 - \Delta f}$ is the unique solution of $v_1^2 - 10v_1 + 13 + 4\Delta f = 0$. So when $-(2 - v_1) < \Delta f < \min\left\{\dfrac{3}{4}, \dfrac{2(2 - v_1)}{3 - v_1}\right\}$, $\dfrac{\partial p_1^*}{\partial v_1} > 0$ if

$v_1 \in (1, 5-2\sqrt{3-\Delta f}\,]$ and $\frac{\partial p_1^*}{\partial v_1} < 0$ if $v_1 \in (5-2\sqrt{3-\Delta f}, 2)$; when $\frac{3}{4} \le \Delta f \le \frac{2(2-v_1)}{3-v_1}$, $\frac{\partial p_1^*}{\partial v_1} > 0$;

(ii) when $v_o = 1$ and $v_2 = 2$, $p_2^* = \frac{2(2-v_1)-(3-v_1)\Delta f}{5-v_1}$. $\Delta f < \frac{2(2-v_1)}{3-v_1}$ because of $d_2^* > 0$ and $\frac{2(2-v_1)}{3-v_1} < 1$ because of $v_1 \in (1,2)$. As a result, $\frac{\partial p_2^*}{\partial v_1} = \frac{-6+2\Delta f}{(5-v_1)^2} < 0$.

The above proposition implies that, how the usability of commercial open source software affects its equilibrium price depends on the difference in the level of features between open source and proprietary software. When the difference is large, the equilibrium price of commercial open source software will increase in its software usability as in Fig. 3. When the difference is small, the equilibrium price of commercial open source software may obtain the maximum value at $v_1^* \in (0,1)$ as in Fig. 5. In the second case, the commercial open source provider doesn't have incentives to improve software usability to the level of competing proprietary software. This is because if commercial open source software' usability is sufficiently close to that of proprietary software then it has to face more intense price competition. Moreover, the equilibrium price of proprietary software lowers as the usability of commercial open source software increases as in Fig. 4 and Fig. 6.

Proposition 3. when $\Delta f = 0$, there are:

(i) d_o^* decreases in v_1; d_1^* and d_2^* increases in v_1;

(ii) π_1^* increases in v_1 if $v_1 \in (1, \frac{11}{7}]$ and decreases in v_1 if $v_1 \in (\frac{11}{7}, 2)$; π_2^* decreases in v_1.

Proof.

(i) when $\Delta f = 0$, $\frac{\partial d_o^*}{\partial v_1} = -\frac{3}{(5-v_1)^2} < 0$, $\frac{\partial d_1^*}{\partial v_1} = \frac{1}{(5-v_1)^2} > 0$ and $\frac{\partial d_2^*}{\partial v_1} = \frac{2}{(5-v_1)^2} > 0$;

(ii) because $\frac{\partial \pi_1^*}{\partial v_1} = \frac{11-7v_1}{(5-v_1)^2} > 0$ when $v_1 \in (1, \frac{11}{7})$ and $\frac{\partial \pi_1^*}{\partial v_1} = \frac{11-7v_1}{(5-v_1)^2} < 0$ when $v_1 \in (\frac{11}{7}, 2)$, and $\frac{\partial \pi_2^*}{\partial v_1} = \frac{-4(v_1+1)}{(5-v_1)^2} < 0$.

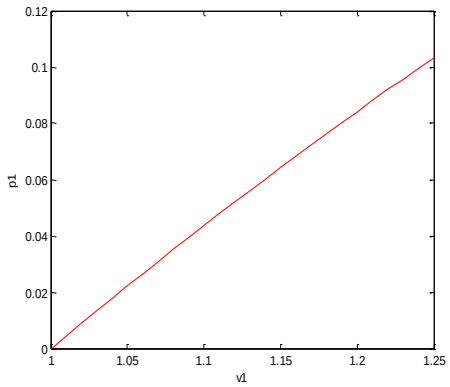

Figure 3. How v_1 affects p_1^* when $\Delta f = 0.8$.

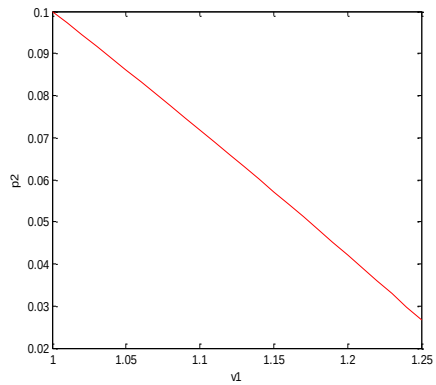

Figure 4. How v_1 affects p_2^* when $\Delta f = 0.8$

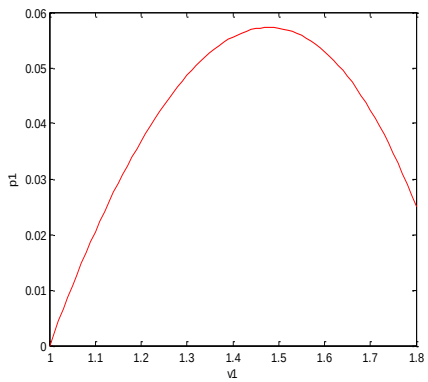

Figure 5. How v_1 affects p_1^* when $\Delta f = -0.1$.

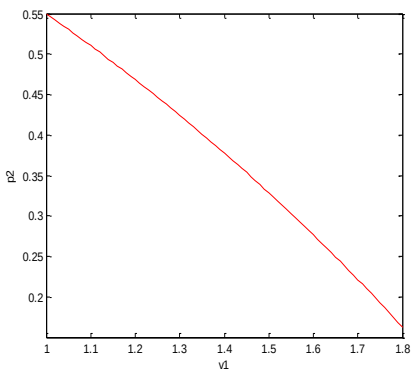

Figure 6. How v_1 affects p_2^* when $\Delta f = -0.1$.

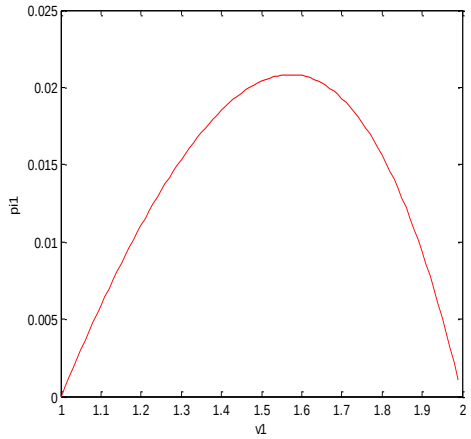

Figure 7. How v_1 affects π_1^* when $\Delta f = 0$.

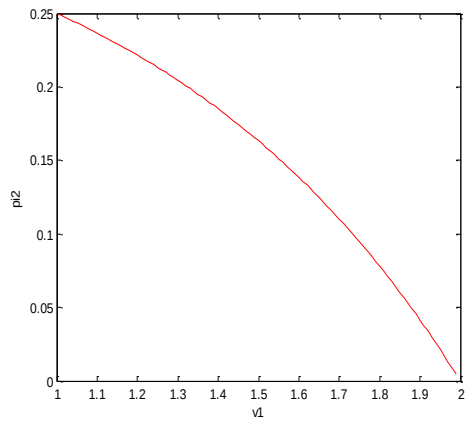

Figure 8. How v_1 affects π_2^* when $\Delta f = 0$.

The above proposition implies that, when the features level of commercial open source software equals that of proprietary software, the share of free open source software (resp. commercial open source and proprietary software) decreases (resp. increases) as the usability of commercial open source software increases. Note that the share of proprietary software doesn't decrease as the usability of commercial open source software increases. The reason is that proprietary provider will lower its software price when the usability of commercial open source software increases and this guarantees it obtain more share. Moreover, commercial open source provider's profit increases (resp. decreases) in its software usability if the usability is small (resp. big) as in Fig. 7. Finally, the profit of proprietary provider decreases as the usability of commercial open source software increases as in Fig. 8.

V. Summary and Conclusions

By extending a vertical differentiation model, this paper analyzes competition between open source and proprietary software. There are two types of open source software in the market, one of which is from the not-for-profit community and the other is from the commercial open source vendor. Free open source software can be freely available, but commercial open source software isn't free. Commercial open source and proprietary software vendors carry on price competition. According to the equilibrium results, we mainly find that: (i) commercial open source vendor may be able to obtain profit when facing competition from proprietary software with higher usability and free availably open source software; (ii) even if commercial open source vendor in terms of software functionality is not inferior to proprietary vendor, its pricing, share and profit may still be much lower than that of proprietary vendor; (iii) the pricing and profit for commercial open source vendor may not increase in its usability, and the price for proprietary software decreases in the usability of commercial open source software.

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