Magnetic Strategy of Proprietary Software Vendors: Leveraging Service Market to Compete with Open-Source Software in the AI-Driven Software Arena

Zerong Wang
Tongji University
2230378@tongji.edu.cn

Xueqi Wei
Fudan University
weixueqi@fudan.edu.cn

Zhe Qu
Fudan University
quz@fudan.edu.cn

Abstract

In the digital economy, the role of the service market is increasingly important. It is the services that not only add value to software products but also drive competitive strategies. For example, artificial intelligence (AI), offers a big arena in the relationship of software and services for the competition between proprietary software (PRS) and open-source software (OSS). This study discusses the role of service market in the competition and how proprietary software vendors (PRVs) tailor its quality strategy under the influence of service market. Specifically, we find that PRVs would adopt the "Magnetic Strategy", that is, when the quality of OSS is below certain threshold, the quality of PRS and OSS "attract" each other; when the quality of OSS exceeds the threshold, the quality of PRS "repel" that of OSS. Furthermore, we also show that a decreasing service development efficiency would motivate PRVs to improve the quality of PRS.

Keywords: Open-source software, Competitive strategy, Services market, Non-cooperative games

1. Introduction

In the domain of digital technology, the competition between open-source software (OSS) and proprietary software (PRS) remains a persistently prominent and relevant subject. Recently, with the widespread implementation of Large Language Models (LLMs) in artificial intelligence, numerous entities have launched proprietary AI software product, including OpenAI's GPT 4, Baidu's Ernie 4, Anthropic's Claude 3 and Google's Gemini. Conversely, other organizations have opted to provide open-source software product, such as Meta's Llama 3, Alibaba's Qwen and xAI's Groq. The fierce competition between OSS and PRS in the artificial intelligence sector attracts considerable attention from both practitioners and researchers. The release of Meta's open-source Llama 3 on April 19, 2024, escalated this rivalry, particularly with OpenAI's proprietary ChatGPT 4. In response, OpenAI unveiled its latest flagship model, GPT-4o, on May 13, 2024. Despite the evident competition, the underlying motivations and the mechanisms driving these dynamics remain obscure. Our research posits that the significant potential of the AI complementary service market provides a more comprehensive explanation for the dynamics of this competition.

When most people pay attention to the explicit competition in primary software market between open-source and proprietary software, the potential of secondary service market in AI is largely overlooked. To illustrate, primary software market sells fundamental software products and secondary software market sells a series of value-added subsequent services complementary with the software product include the integration, support, customization and consulting offerings (August et al., 2021). For example, in AI context primary software market refers to the selling of Large Language Models licenses and subscriptions, such as the purchasing of ChatGPT plus and GPT-4o API. Significantly, there is a secondary service market with substantial profit potential associate to AI software products. Such services involving deployment, assessment, ongoing maintenance, privacy and security services, fine-tuning, customization, plugin assistant tools and so on. According to Willing (2024), revenue from the secondary service market complementary with LLMs primary software market plays a crucial role in OpenAI's financial success. For OSS players in the AI context such as Llama and Qwen with free access

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to adopting the LLMs software, secondary service market is evidently among the most important sources of revenue. Thus, existence of secondary service market may significantly impact the primary software market competition between OSS and PRS.

In previous research, although scholars have highlighted the importance of complementary services in the market competition between OSS and PRS, these studies focus on the traditional software context, such as enterprise management software. However, existing literature modeling the service market complementary with the traditional software market fails to effectively explain the impact of complementary service market on the competition dynamics between OSS and PRS in the AI context. This is because previous literature often lacks the capture of key parameters in the service market, such as service development costs and service development efficiency. Therefore, the literature is limited to fully explore and characterize the service market. In the context of traditional software, for simplification, services such as integration are assumed to have uniform costs per unit for each vendor (August et al., 2021). However, in the AI context, there may be significant differences in service development cost and service development efficiency between different vendors. For example, in terms of fine-tuning and customization services, LLMs vendors offer such services to vertical industry for enterprise users. The service development efficiency varies significantly based on the heterogeneous of parameter sizes of LLMs adopted. Therefore, the service development efficiency in general has been an increasingly critical issue in practice which cannot be oversimplified and ignored. Motivated to fill this gap, this study highlight the analysis of service development efficiency.

Given the increasingly importance of service market, in this research we build analytical models to explore the mechanism of competition between open-source and proprietary software under the impact of the service market. Several interesting research questions arise from the competition between OSS and PRS:

- What is the impact of the advancement of OSS quality on the strategic decision of PRS quality under the influence of the service market?
- What is the impact of the service development efficiency ratio on the strategic decision of PRS quality?
- How does the service development efficiency ratio influence the strategic decision of PRS quality in responce to the advance of the OSS quality?

To conclude, the service market paves the way for a business model paradigm shift in software competition motivated by the advance of digital technology. By building a three-stage duopoly model, we answer these questions and try to understand the service market, the driving force underlying the software competition between OSS and PRS. We explore the dominant logic of the transformation of business model and the change of competitive structures. Based on our analysis, we provide the managerial implications for the explanation of the current corresponding activities in the LLMs context, thus leading to the future insights for business model.

2. Literature review

The complementary product/service strategy has been brought up in several studies. For example, Sen (2007) underscores the significance of the service market, as the model posits that OSS with support services (OSS-SS) represents a product with greater usability than conventional OSS due to the inclusion of supportive services. In another example, August et al. (2013) delve into how OSS licensing policies propel firms towards either open-source or proprietary development strategies based on the economic incentives tied to the software services market. Similarly, August et al. (2018) claims that licensing attributes are instrumental in steering software originators' decisions that enhance open-source outcomes and societal welfare, suggesting policies to incentivize welfare-improving open source strategies. Drawing from these regulatory foundations, August et al. (2021) explore the three-party dynamics of OSS contributors, originators, and proprietary competitors. Their analysis suggests that licensing restrictiveness crucially dictates the extent of competitive efforts and investments, ultimately impacting consumer surplus and social welfare. While the licensing architecture sets the stage, Wang et al. (2020) and August et al. (2021) pivot the focus towards the resulting strategic plays among OSS and PRS firms. Wang et al. (2020) constructs duopoly model which illustrates scenarios where PRVs may leverage the presence of OSS to their advantage under certain market conditions.

However, these papers focus on the open-source software perspective with services market while our paper examines the software quality decision of PRVs. From the perspective of PRVs decision-making, Zhou and Choudhary (2022) explores the impacts of OSS competition on the optimal design of PRS quality. It is found that under certain conditions, OSS competition may lead to a deterioration in PRS quality compared to a monopolistic scenario. However, when the costs of quality increasing are moderate, OSS competition can prompt PRVs to enhance PRS quality (Zhou and Choudhary, 2022). Our research benefits from these findings and extend their model by incorporating the service market to discuss the software quality decision of PRVs. Critically, economic modeling literature with regard to the software competition involving services often fails to fully capture key parameters of the service market, leading to limitations in characterizing the service market accurately. This study fills the gap by examing the impact of the service development efficiency.

The modeling framework of this paper differs from that of existing literature, providing contributions in several aspects. Firstly, prior literature has predominantly focused on the cost-saving effects of open-source software in software development (Wang et al., 2020). However, the main stream of the commercial OSS business model highlights the significance of services market where "profit-driven firms generate revenue primarily from a market for professional services" (August et al., 2021). The service costs associated with open-source software cannot be overlooked. Secondly, previous studies assume that the unit cost of providing the integration and services work is the same for each OSS and PRS provider, therefore neglecting the service cost and its efficiency (August et al., 2018; August et al., 2018; August et al., 2021). Nevertheless, fueled by AI technology, the service development efficiency becomes an increasingly critical issue. Hence, this study examines its impact on competition. Additionally, in contrast to existing papers consider the intertwined and bundled total quality of software and services (Arora and Bokhari, 2007; Llanes and de Elejalde, 2013), our study takes a different approach by focusing on the endogenous nature of service quality. Finally, while some studies assume consumers have horizontal preference for software (Wang et al., 2020; Kim and Hyun, 2011; Batra et al., 2012), our model emphasizes quality-based preference (Bhargava and Choudhary, 2001), and the preferences of software and services are independent, which means consumers can have different taste for services. These model settings give a better characterization of the service market and enable us to explore the influence of the services market on competition which have not been adequately addressed in the existing literature.

3. Model setup

In our model, we assume there are one proprietary software vendor (PRV) and one open source software (OSS) service provider in a market offering competing software as well as consequent services. The PRV sells both software license and service for its proprietary software (PRS), while the OSS service provider only sells OSS service because OSS is usually available for users free of charge. The market competition framework proposed in this paper benefits from the foundational assumptions established by Zhou and Choudhary (2022). In their assumptions, Zhou and Choudhary (2022) emphasizes PRVs compete primarily through pricing and software quality, with user choices grounded in a trade-off between these two factors. This indicates that software quality is a significant determinant. Our model retains this assumption and we assume that both the software quality and the service quality are vertically differentiated. Let $q, Q \in [0, \overline{q}]$ where $\overline{q}$ represents the highest quality of the PRS for the PRVs to earn a non-negative profit.

In light of the practice, there is always accessible to download the OSS from its website for free, which indicates the OSS quality is observable for the public. Furthermore, every contributor in the OSS community can potentially contribute to the improvement of OSS quality and the OSS is maintained by the community. Hence, there is few strategic power from one specific individual or vendor who can determine the ultimate OSS quality dominantly. Therefore, we assume that the quality of OSS is exogenous. Following Thatcher and Pingry (2004), we have the following assumption for the development costs $C(q)$ of the PRS and the quality of PRS is subject to the following assumption of the development cost:

Assumption 1 *The development cost $C(q)$ of the PRS is twice differentiable where $C'(q) > 0$ and $C''(q) > 0$. Specifically, we have $C(q) = aq^2$ where $a > 0$.*

Building upon foundational model of Zhou and Choudhary (2022), in addition to the price and quality of software, we further hypothesize that the service market is a critical factor influencing the users choices between PRS and OSS. In this regard, Sen (2007) assumes that open source software with support services (OSS-SS) represents a product with greater usability than conventional OSS due to the inclusion of supportive services. The discussion of software usability highlights the importance of service market in influencing user choices regarding software (Sen, 2007). Consequently, inspired by such assumption that the service market emerges as a critical consideration in user selection, we extend the model to further investigate the specific mechanisms through which the service market influences the software market competition. This is particularly relevant in AI-driven LLMs scenarios, where many users are corporate clients or advanced research institutions. These users require services that extend beyond mere technical support to include customized solutions, highly specialized consulting services, and real-time responses. However, simply reflecting the usability of software does not adequately capture the role of the service market. Thus, our model introduces parameters related to service development cost efficiency, enabling us to elucidate how the service market impacts market competition and, consequently, the quality decisions made by PRVs.

As information goods, after the development of the PRS and OSS, the marginal cost of producing an additional copy of either good is trivial and is assumed to be zero in our model. The software services provide additional value to software users. The PRV chooses service price p_s for the PRS, and the OSS service provider determines the service price p_s^o for the OSS. In the same way, we presume that the service development costs of the PRS and OSS are respectively $C_s^p = bq_s^2$ and $C_s^o = cQ_s^2$, where $b > 0$ and $c > 0$. Let $k = \frac{b}{c} > 0$ represent the service development cost efficiency ratio of PRS relative to that of OSS. Note that the higher the service development cost efficiency ratio k, the lower the service development efficiency of PRS would be. To indicate, in practice open-source models sometimes possess an advantage over closed-source models in terms of higher service development cost efficiency. This is because open-source LLMs typically have smaller parameter sizes, requiring less computational power and data. In contrast, closed-source LLMs, compared to open-source models, incur significantly high costs in developing customized services due to their characteristics of large parameters and scale. Therefore, service development cost efficiency varies in different types of software. The PRS users purchase service from the PRV, and the OSS users purchase service from the OSS service provider if their net surplus of purchasing the service is positive. Service qualities of the PRS and the OSS are denoted as q_s and Q_s, respectively.

Consumers have demand for both the software and the consequent services. We denote a consumer's taste for software quality as θ and that for service quality as θ_s. Both θ and θ_s are uniformly distributed over the interval [0, 1]. We assume a consumer's tastes for software quality and for service quality are independent of each other because taste for software quality can be based on a consumer's income while taste for service quality can be based on a consumer's technological capability and experience using the software. Denoting $U(\theta, q)$ as a consumer θ's utility of software with quality q and $U(\theta_s, q_s)$ as a consumer θ_s's utility of service with the service quality q_s, we have the following assumption:

Assumption 2 *A consumer's utility of software quality is the product of the taste for software quality and the quality of the software, and a consumer's utility of service quality is the product of the taste for service quality and the quality of the service. Equivalently,* $U(\theta, q) = \theta q$ *and* $U(\theta_s, q_s) = \theta_s q_s$.

Following industry practice, we model the decision-making process of the players as a non-cooperative game in each scenario and we work backward to solve it. We first show the market segmentation in the presence of service market as follows:

Lemma 1 *PRV would always take the high-end of the market by setting* $q > Q$.

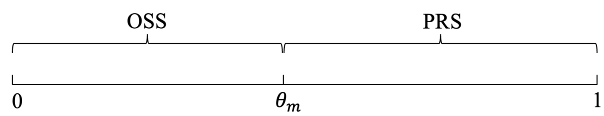

Figure 1. Market Share of OSS and PRS

This situation is often observed in the real-world practice. For example, in the current LLMs market, taking OpenAI as an example, OpenAI develops proprietary solutions, capitalizing on algorithmic expertise, synergizing with Microsoft's computational resources and data. This strategic pivot enables OpenAI to seize a commanding position in the high-end segment of the LLMs market. Overall, the trend indicates that open-source models are catching up with proprietary models. In light of the market segmentation proposed in lemma 1, we formulate the problem as a Stackelberg game and establish the existence and uniqueness of Nash equilibrium under sufficient conditions. The sequence of events unfolds as follows:

- In Stage 1, there is one OSS in the market with exogenous quality Q, and the PRV observes Q to determine the quality level q of its PRS. This is reasonable in the LLMs context. For example, Google established the precedent for open-source practices, exemplified by their early open-source models, such as Transformer, Bert and T5. Then some proprietary models were subsequently developed by PRVs such as OpenAI.
- In Stage 2, the OSS is offered free, and the PRS is associated with a price p. Each consumer acquires one and only one copy of the software from either the OSS community or the PRV (because the OSS is offered free, the software market is fully covered).

- In Stage 3, the PRV or the OSS service provider determines the service quality levels to serve their relevant market. The price of either PRS service or OSS service is determined accordingly.

Using backward induction, we start by characterizing the equilibrium of the second stage. Consumers make service adoption decisions based on their expectation since they do not know their own requirements for service quality by lack of insight into themselves. We derive their expected surplus of using the PRS service and the OSS service as the following:

$$A = \int_{\frac{p_s^*}{q_s^*}}^{1} \left(\theta_s q_s^* - p_s^*\right) d\theta_s = \frac{D}{64b}, \tag{1}$$

$$B = \int_{\frac{p_s^{o*}}{Q_s^*}}^{1} \left(\theta_s^o Q_s^* - p_s^{o*}\right) d\theta_s^o = \frac{D^o}{64c} \tag{2}$$

The consumers' expected total surplus of choosing the PRS is

$$U^{PRS} = \theta q - p + A \tag{3}$$

$\theta q - p$ is the surplus of consuming the software and A is the expected surplus of adopting the PRS service. Consumers' expected total surplus of adopting the OSS is

$$U^{OSS} = \theta Q + B \tag{4}$$

The indifferent consumer θ_m is defined by $U^{PRS} = U^{OSS}$, where we have

$$\theta_m = \frac{p - \frac{1}{64}\left(\frac{D}{b} - \frac{D^o}{c}\right)}{q - Q} \tag{5}$$

The demand for the PRS is

$$D = 1 - \frac{p - \frac{1}{64}\left(\frac{D}{b} - \frac{D^o}{c}\right)}{q - Q} \tag{6}$$

The demand for the OSS is

$$D^o = \frac{p - \frac{1}{64}\left(\frac{D}{b} - \frac{D^o}{c}\right)}{q - Q} \tag{7}$$

The PRV's payoff in Stage 2 is $\pi = \pi(software) + \pi(service)$ where $\pi(software) = pD - aq^2, \pi(service) = p_s^* D_s^* - b q_s^{*2} = \frac{D}{64b}$. The PRV's problem in Stage 2 is to

$$\max_p \pi = pD + \frac{D}{64b} - aq^2 \tag{8}$$

The PRS price and the software market share at equilibrium satisfy

$$p^* = \frac{\left[-3c + b\left(-1 + 64\,c(q-\theta)\right)\right]\left[-1 + 64\,c(q-\theta)\right]}{128c\left[-2c + b\left(-1 + 64c(q-Q)\right)\right]} \tag{9}$$

$$D^* = \frac{1}{2} - \frac{c}{b + 2c + 64bc(Q-q)} \tag{10}$$

$$D^{o*} = \frac{1}{2} + \frac{c}{b + 2c + 64bc(Q-q)} \tag{11}$$

The PRV's objective in Stage 1 is to

$$\max_q \pi = p^* D^* + \frac{D^*}{64b} - aq^2 \tag{12}$$

where $p*$ and $D*$ are determined in Stage 2. Substitute $p*$ and $D*$ into the expression above to obtain the profit function concerning q. The equilibrium quality of the PRS satisfies

$$\frac{1}{4} - \frac{c^2}{\left[b + 2c + 64bc(Q-q)\right]^2} - 2aq \; = 0 (FOC) \tag{13}$$

when the PRV's payoff function is quasi-concave, that is, $-\frac{128bc^3}{[b+2c+64bc(\theta-q)]^3} - 2a < 0$ (SOC). Substituting q* into the expressions for $p*$ and $D*$ in Stage 2 and into the expressions for p_s^* and p_s^{o*} in Stage 3, we derive in equilibrium the PRS price, the market share of the PRS and the OSS, and the service prices of the PRS and the OSS.

4. Analysis

In this section, we analyze the impacts of OSS quality Q and the service development efficiency ratio k on PRVs' software quality decision based on the model proposed in *Section 3*. We investigate three questions: we first examine the impact of OSS quality on PRVs' software quality decision under the influence of the service market, and then analyze the impact of the service development efficiency ratio on PRVs' software quality decision. Finally, we investigate how the service development efficiency ratio influence the impact of OSS quality on PRVs' strategic quality decision.

4.1. Impact of OSS quality on PRV's software quality decision

The main objective of our analysis is to characterize how the PRVs' software quality decision would change with the quality improvement of OSS when the service market exists. To clearly illustrate the strategic role of service market in the dynamic PRVs' software quality decision under the influence of OSS quality, we divide this section into two groups: the impact of OSS quality improvement on PRVs' software quality decision with and without the service market.

4.1.1. Without service market. We first analyze the benchmark case where no service market exists, therefore we have $q_s = Q_s = 0$. In this scenario, our problem degenerates to the traditional duopoly price competition with vertical differentiation. Specifically, the game can be formulated as follows. In Stage 1, the PRV determines the selling price p, to maximize its profit. In Stage 2, the consumers will either purchase the ownership of a product PRS or adopt OSS for free.

Lemma 2 *For the proprietary software without the service market, the improvement of the OSS quality would hurt the PRS profit though there is no influence on the market share structure and the optimal quality of the PRS.*

In the benchmark scenario, as OSS quality improving, PRVs will always set an optimal software quality at a specific level to make a trade-off between the the increasing development cost and the benefit of quality improving. PRVs would always take over the high end of the market and leave the half market share to OSS. Although this market structure would remain unchanged, PRVs would be actually worse off induced by the quality improvement of OSS.

4.1.2. With service market. We next reveal how the service market would affect PRVs' software quality decision in response to the improvement of OSS quality. What is the mechanism of the PRVs' software quality decision dynamics influenced by the service market? We answer this question below.

Proposition 1 *For software with the demand for service, when Q is less than a threshold $\underline{Q} = \frac{8ck-a(3+k)+4\sqrt{2ack}}{64ack}$, the optimal quality of the PRS q^* is the optimiazation in Equation (13):*

$$q^* s.t. \{q^* : \frac{1}{4} - 2aq - \frac{1}{(2+k+64ck(-q+Q))^2} = 0\} \tag{14}$$

the PRV lowers the quality of the PRS as the quality of the OSS increases. When Q exceeds the threshold, the PRV would set the software quality at $\underline{q} = \frac{4+k}{64ck} + Q$ where the PRV improves the quality of the PRS as the quality of the OSS increases.

Proposition 1 implies a *Magnetic Strategy* in PRVs' software quality decision with the service demand. When the quality of the OSS is below a threshold $\underline{Q}$, the higher the quality of the OSS, the lower the quality of the PRS would be. As Figure 2 illustrated, this situation resembles one in which the position of the PRS (in terms of quality) is attracted to that of the OSS. If the quality of the OSS exceeds the threshold, the quality of the PRS is placed at the corner solution $\underline{q}$ which increases with the quality of the OSS as if the two repel one another.

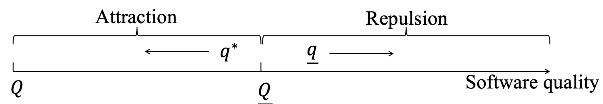

Figure 2. Illustration of Magnetic Strategy

The magnetic strategy highlights the strategic role of the service market, the "invisible hand", in the software arena. Firstly, we analyze the mechanism of the attraction region. The magnetic strategy argues that the improvement of the OSS quality counter-intuitively leads to a lower PRS quality when the OSS quality is relatively low ($Q < \underline{Q}$). The hidden agenda of such deviation from traditional expectations lies in the service market. Traditional theory, focused on the software market competition, would predict that the PRS quality would be enhanced to differentiate it from the OSS competitor. However, the presence of the service market introduces more dynamics into the software competition. To make an effective PRS quality decision, it is required for PRVs to make a trade-off between the benefit of the software market and the loss of the service market in profit. That's because the improvement of the PRS quality brings the marginal benefit in the software market, while it would cause the software market share of the PRS decreasing as figures 1 shown. Note that the decrease of the software market also means the decrease of the service market due to lock-in effect. Hence, the decrease of the software market share (so does the service market share) leads to a loss in the service market. Therefore, the positive effect on the profit of the software market would be potentially offset by the negative effect on the profit of the service market. Following discussion examines how the OSS quality would have an impact on such two opposing forces. Specifically, an increase in the OSS quality Q would potentially motivate the improvement of the PRS quality for the more marginal profit in the software market (i.e.,$\frac{\partial^2 \pi_1}{\partial q \partial Q} > 0$). However, such impact of the OSS quality would also intensifies the negative effect on the service market profits of PRVs (i.e.,$\frac{\partial^2 \pi_2}{\partial q \partial Q} < 0$). Significantly, the more serious negative impact on the service market outweighs the enhancement of the positive effects on the software market (i.e., $\left|\frac{\partial^2 \pi_2}{\partial q \partial Q}\right| > \left|\frac{\partial^2 \pi_1}{\partial q \partial Q}\right|$). That means a higher sensitivity of the PRS service market loss to the impact of the OSS quality than the sensitivity of the PRS software market benefit, attributed to a great market share effect. As a result, the PRVs would carefully adjust the optimal quality to strategically keep the equilibrium between the variation of the software market with that of the service market.

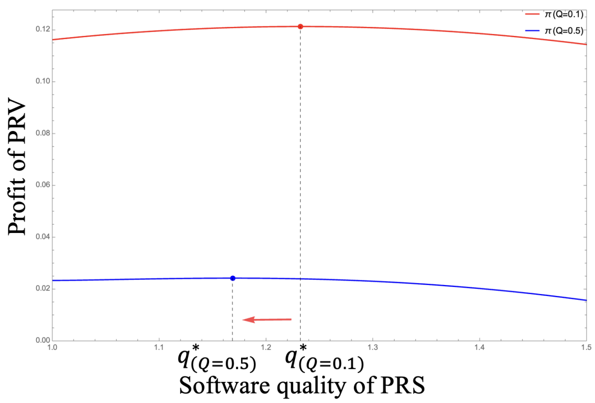

Figure 3. Profit of PRV with Software Quality

Overall, in terms of the attraction region, although the improvement of the OSS quality hurt the PRS, a direct loss of profit, the adjustment of the PRS quality makes it up as Figure 3 shown. The dominant driving force of service market mitigates the decline in overall profit of the PRVs. In the database management system market, for example, shortly after the release of MySQL version 5.0, which incorporated significant functionalities into the DBMS, Oracle Corporation launched a low-end, complimentary proprietary database in October 2005, purportedly in response to the intense competition from burgeoning low-end open-source databases. In addition, some customers have remarked that GPT-4 (PRS) has become "inept." It is found that noticeable performance declines in GPT-4 in March and June 2023 when compared across four tasks: mathematical problem-solving,sensitive question answering, code generation, and visual reasoning. Our model casts a light on this intriguing phenomenon. This phenomenon is not only driven by PRV's endeavor to balance the quality and the cost for profit augmentation but also represents a decision made to cope with OSS's persistent advancement.

Moreover, considering the repulsion region where Q exceeds a specific threshold, the condition in Equation (13) is binding, allowing a corner solution of the PRS $\underline{q} = \frac{4+k}{64ck} + Q$ which increases with Q. Under this condition, the PRVs would adopt an aggressive strategy to maximize the software market share (so does the service market share), forcing the OSS to quit the market. This arises because when Q is relatively high ($Q > \underline{Q}$), the marginal benefit in the software market is not enough to compensate the significant development costs of the quality enhancement and the great loss in the service market profit. Therefore, the PRVs tend to capture as much the software market share as possible, expanding the service market which are considered as the main battlefield for profit under the condition of $Q > \underline{Q}$.

In summary, by comparing the PRVs' quality decision with and without the service demand, we conclude that it is the service market that plays a strategic role in the quality decision, that is, pulling the PRS position (in terms of the quality) towards the OSS or pushing it away from the OSS. The mechanism analysis lies in the relative sensitivities of the two markets to the impact of the OSS quality. That is, there is a higher sensitivity of the PRS service market profit to the impact of the OSS quality than the sensitivity of the PRS software market profit.

4.2. Impact of the service development efficiency ratio on PRVs' software quality decision

In this section, we answer the second question: what is the impact of the service development efficiency ratio k on PRVs' software quality decision. The service development efficiency ratio k reflects the power of the service market of the PRS. That means the higher of the service development efficiency ratio k, the lower service development efficiency of PRS would be.

Proposition 2 *For software with the demand for service, when k exceeds a threshold $\underline{k} = \frac{-3a^2+40ac-192a^2cQ+4\sqrt{2(-3a^3c+32a^2c^2-192a^3c^2Q}}{a^2-16ac+64c^2+128a^2cQ-1024ac^2Q+4096a^2c^2Q^2)}$, the optimal quality of the PRS q^* is the optimization in Equation (13):*

$$q^* s.t. \{q^* : \frac{1}{4} - 2aq - \frac{1}{(2+k+64ck(-q+Q))^2} = 0\}, \tag{15}$$

The PRV enhances the quality of the PRS as the service development efficiency ratio k increases; When k is less than the threshold, the PRS quality is set at $\underline{q} = \frac{4+k}{64ck} + Q$.

Proposition 2 shows that the impact of the service development efficiency ratio k on PRVs' software

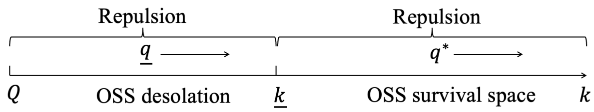

Figure 4. Market Structure with Service Development Efficiency Ratio k

quality decision. As Figure 4 shown, regardless of whether k is above or below the threshold, the quality of PRS will increase with the increase in OSS quality, pushed away from OSS, as if the two are mutually repulsive. Specifically, the quality of PRS would be q^* if k exceeds the threshold. Under this condition, OSS and PRS coexist in the market, with PRS quality improving under the impetus of OSS. On the other hand, the quality of PRS would be $\underline{q}$ if k is lower than the threshold. Under this condition, OSS would be forced to quit the market by an aggressively quality strategy of PRVs, leading to the OSS desolation region. The mechanisms of two quality decisions corresponding to two regions (i.e., above and below the threshold) are as follow. We first explain the mechanism under the condition $k > \underline{k}$ and then follows the mechanism of the condition $k > \underline{k}$.

Firstly, when k exceeds the threshold, with k increasing, q^* also increases as Figure 4 shown. In this scenario, the condition in Equation (13) is not binding, there is an interior optimal solution q^* which increases with the service development efficiency ratio k. Intuitively, improving software quality aims to gain more profits in the software market, implying that this strategy is motivated by the driving force of the software market. However, our findings suggest that the service market makes a great difference in motivating such quality strategy.

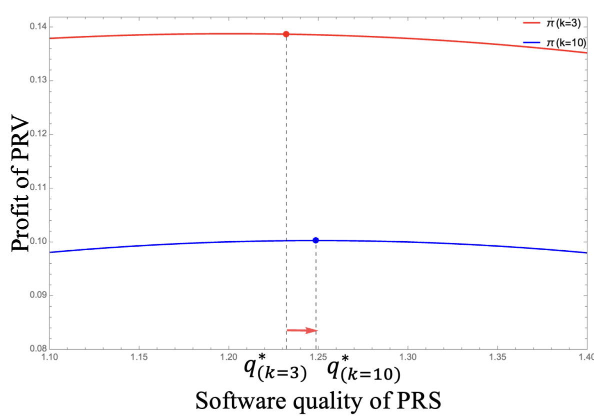

Figure 5. Profit of PRV with Software Quality

The hidden mechanism is as follows: The increase in the service development efficiency ratio k suggests that the service cost of the PRS increases relative to that of the OSS (i.e., lower service development efficiency of the PRS), thereby weakening the leverage power of the service market. The increased service costs hurt the PRS service market. However, such negative effect can be mitigated by increasing the PRS quality. Once again the driving force lies in the service market as a strategic lever of the software market. For example, in the scenario where cost efficiency in open-source LLMs improves, closed-source LLMs vendors do not hold a significant advantage in the service market and will continue to enhance the quality of software markets. In practice, OpenAI remains dedicated to investing in the software market to improve the foundational quality of LLMs.

This occurs because an increase in the optimal PRS quality q^* reduces the sensitivity of the shrinking of the software market share (so does the service market share) due to the increasing service development efficiency ratio k (i.e., lower service development efficiency of the PRS). To be specific, the increase in k (i.e., lower service development efficiency of the PRS) hurts the service market profit in two ways. Firstly, an increasing k means a lower service development efficiency which directly damages the profits of the service market. In addition, an increase in k would lead to a decrease in the software market share (so does the service market share), thereby further damaging the profits of the service market. This is because the service market serves as a strategic lever influencing the software market significantly. The impact of an increasing k would be indirectly transmitted to the software market. Such effect would be reflected in the software price, leading to an increase in software prices and a decrease in software market share (so does the service market share). Significantly, the impact of the rising software pricing exerted by the increase in k can be reduced and mitigated by improving the PRS quality to attract quality sensitive users. In other words, the improvement of the PRS quality reduces the software price growth rate caused by increased k. This quality strategy prevents a sharp rise in prices, thereby reducing the elasticity of demand decline and avoiding a significant contraction in demand. As a result, it weakened and mitigated the damage of the decline in software market share (so does the service market share) to the profit of the service market as Figure 5 shown. This subtle interaction highlights how the service market play a dominant role as a strategic lever influencing the software market decision.

Moreover, when k falls below the threshold, PRVs would adopt a corner solution that aggressively excludes

OSS with the objective of maximizing the software market share (so does the service market share). This is due to the fact that a lower value of k (i.e., higher service development efficiency of the PRS) implies a significant cost advantage for PRS in the service market which harbors substantial profit potential. Consequently, PRVs force their competitors to quit the market, thereby establishing a strong market foundation in the highly lucrative service market. In conclusion, our research argues that PRVs adopt different quality strategies depending on the value of k, especially when it falls below or surpasses a specific threshold, under the influence of the service market.

However, in the scenario where cost efficiency in open-source LLMs improves, closed-source LLMs vendors do not hold a significant advantage in the service market and will continue to enhance the quality of software markets. In practice, OpenAI remains dedicated to investing in the software market to improve the foundational quality of LLMs.

4.3. How the service development efficiency ratio influence the impact of OSS quality on PRV's software quality decision

In this section, we answer the third question: how does the service development efficiency ratio influence the impact of OSS quality on PRVs' strategic quality decision? As discussed previously, we have analyzed the impact of OSS quality on the PRVs' software quality decision, that is, the magnetic strategy where we consider the service development efficiency ratio k as a constant. Next we further explore how the service development efficiency ratio would influence the impact of OSS quality on PRVs' strategic quality decision.

Proposition 3 *The threshold $\underline{Q}$ increases with the service cost ratio k, leading to a shrinking of repulsion region ($Q > \underline{Q}$), while attraction regions ($Q < \underline{Q}$) expand, albeit with a decreasing intensity ($\left|\frac{dq^*}{dQ}\right|$).*

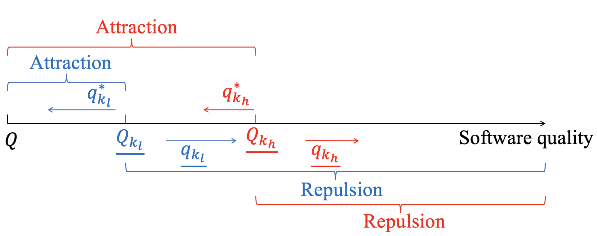

Figure 6. Impact of Service Development Efficiency Ratio k on Market Structure

The region of magnetic repulsion implies that when $Q > \underline{Q}$, PRVs employ pricing strategies to maximize their software market share (so does the service market share), prioritizing the service market as the core source of profit. When k increases (i.e., lower service development efficiency of the PRS), it suggests that the bonus of the service market reduces, therefore the repulsion region with service market as the main battlefield shrinking. Additionally, in situations where $Q < \underline{Q}$, the focus shifts to leveraging the service market in response to the potential threat posed by an increased Q in the software market, aiming to offset the losses inducing of increasing Q, which motivates the attraction strategy. As k increasing, the leverage exerted by the service market weakens, indicating a diminished intensity of attraction, although the attraction region expands.

5. Conclusion

Although prior studies have noted the importance of OSS in many areas of software development, very little was found in the literature on the question of software characterized by significant demand for service. Previous literature, which explores the impacts of OSS competition on the optimal design of PRS quality, find that, under certain conditions, OSS competition may lead to a deterioration in PRS quality compared to a monopolistic scenario. However, when the costs of enhanced quality are moderate, OSS competition can prompt PRVs to elevate PRS quality (Zhou and Choudhary, 2022). While these findings primarily focus on the primary software market, this paper expands on them by introducing service development cost efficiency to discuss how the service market impacts the optimal design of PRS quality in light of OSS competition. Our findings show that PRVs would adopt the "Magnetic strategy" in PRS quality decision under the impact of the service market. Furthermore, we further discusses the impacts of the service development cost efficiency on the "Magnetic strategy". Finally, this paper provides managerial implications for PRVs which also shed new light on the rationale of PRVs' observed activities in the LLMs contexts that the existing literature has not adequately explained, thus providing future insights for business model.

There are several directions for future research. This study focuses on the competition between OSS and PRS, and we assume monopoly PRV in the model. In future research, we may add competition among PRVs. This perspective allow the study of competitive dynamics among PRVs due to the emergence of OSS. We may also relax the assumption that the quality of OSS is exogenous. This will lead to a different set of research questions regarding cooperation and competition between OSS and PRVs. We did not include software's switching cost and network effect in the model, while both types of software examined in the model may exhibit network effect and have substantial switching costs. Including them in the model will complicate the model and interfere with our key focus. Future research may analyze the impact of these effects on the implications of the model. Intuitively network effect and switching cost may prevent users from adopting OSS or switching to OSS even if OSS is priced at zero.

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