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Open source software subsidies and network compatibility in a mixed duopoly

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Abstract

Open source software (OSS) generally offers a high-quality alternative to proprietary software (e.g. Linux, Apache, Android, etc.) for many applications. Although OSS is usually free of charge, its diffusion remains limited. Should government intervene to promote the diffusion of OSS, and offer potential adopters some learning or financial support? This paper examines whether public subsidies for OSS are socially desirable, and how the extent of compatibility between OSS and proprietary software (PS) might influence the optimal subsidy offered. We consider a mixed duopoly model in which a PS company competes with an OSS community. Users are heterogeneous in their ability to use OSS, and their utility depends on the number of users who adopt the same or compatible software (existence of network externalities). Four situations are distinguished: full compatibility between OSS and PS, full incompatibility, and one-way compatibility (either only OSS or PS is compatible). We show that if the government places more weight on consumer surplus, public subsidies are welfare-enhancing. But the optimal subsidy level is larger with full compatibility and PS compatibility than full incompatibility and OSS compatibility. These results suggest that government policy towards OSS should be conditional on the degree of compatibility between PS and OSS.

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1. Introduction

Since the early 2000s, several governments around the world have been actively encouraging adoption of open source software (OSS)[1], mainly through training programs and direct procurement (e.g. for public administrations and schools). There are several reasons for promoting OSS (Varian and Shapiro, 2003; Benkler, 2002; Smith, 2002). First, OSS (e.g. Linux, Apache, Gimp, Sendmail, etc.) is available free of charge and is perceived as more secure, reliable, and customizable than proprietary software (PS). Second, it may level the software industry playing field, and correct market failures arising from the demand and supply characteristics of the industry (switching costs, network effect, ...). A typical example is Linux, which is an alternative to Windows in the market for operating systems: Linux has fewer bugs and is more frequently updated than Windows (Raghunathan et al., 2005). However, despite its superior quality, the diffusion of Linux is limited to a population of expert users. The vast majority of users prefer to buy PS which tends to be more user-friendly and offers technical help and support.[2]

This article examines whether public policy in favor of OSS can be efficient, and how it impacts users and PS companies. Here we focus on public subsidies to reduce the cost of users' OSS adoption[3] (i.e. the costs of installing and using OSS). We address the questions of (i) what is the welfare impact of public subsidies for OSS? (ii) how can the extent of compatibility between PS and OSS affect the optimal subsidies?

The open source (OS) literature provides mixed results about the welfare impact of subsidies for OSS use. Schmidt and Schnitzer (2002) show that such a policy reduces the software company's incentives to improve the quality of its product and has detrimental effects on welfare. Comino and Manenti (2003) consider a market in which some users ignore the existence and/or characteristics of OSS. They find that OSS subsidies always reduce social welfare whereas mandated adoption and information provision can be welfare-enhancing. In contrast, Mustonen (2003) finds that public efforts to provide better information on open source alternatives are welfare enhancing.

This paper revisits this issue in a different setting. We develop a two stage model in which first government chooses the subsidy level, then the software company sets the price of its product, and finally customers choose between the PS and the OSS alternative that is released free of charge (mixed duopoly)[4]. We suppose that the two software types (PS and OSS) can be compatible or incompatible. Moreover, customers are heterogeneous in their ability to use OSS, and their utility increases with the number of users who adopt

[1] OSS is software for which the source code is freely available, and the license under which is it distributed enables every user to not only use the software, but also to copy it, modify it, and redistribute the original or modified version to other users.

[2] Network effects can hinder the entry of higher quality software. Network effects arise both directly from the number of consumers who are using compatible software and indirectly from the provision of complementary services. Network effects can tip the market in favor of only one software product. This can happen for any product or technology with network externality. For instance, it can explain the dominance of the QWERTY keyboard despite its lower performance than Dvorak's simplified keyboard (David, 1985).

[3] There are other policies to promote OSS. For instance, Comino and Manenti (2005) compare the efficiency of three forms of government intervention: subsidy, mandated adoption of OSS for public administrations, schools, etc... and provision of information to users.

[4] In the line with Casadesus-Masanell and Ghemawat (2006), mixed duopoly refers, in this paper, to the interactions between a not-for-profit competitor (OS community) and a for-profit competitor (PS firm).

the same or a compatible software (i.e. presence of network effects). Four situations are distinguished: full (two-way) compatibility, incompatibility, and two situation of one-way compatibility (either OSS or PS compatibility). OSS compatibility means that the PS users unilaterally can access the OSS community and derive benefits from it. For instance, they can use programs developed by the OSS community, or read and modify the files sent by OSS users, whereas the OSS users cannot open the files or programs created using PS. With PS compatibility, only OSS users are able to derive some utility from PS users.[5] The objective of the paper is to compare the optimal subsidy policy and competitive outcome in these four compatibility regimes.

We show that public subsidies are welfare-enhancing if government puts sufficient weight on consumer surplus. Moreover, the optimal level of subsidies is higher under full compatibility and OSS compatibility than under full incompatibility and PS compatibility. These results suggest that government policies to promote OSS must be conditional on the degree of compatibility between PS and OSS.

The paper is organized as follows. Section 2 presents the model. Section 3 derives and compares the equilibrium outcomes and optimal subsidies under the four compatibility regimes. Section 4 discusses the limitations of this study and possible extensions.

2. Model Setting

We consider a firm that sells a PS of quality, V_{PS}, at price, p. Consumers have an alternative of OSS developed by an OS community. This software is free and has a level of quality, V_{OS}. We assume that $V_{OS} \geq V_{PS}$ meaning that the OSS never has a lower intrinsic quality or performance. This is not a very restrictive assumption since it includes the situation where the quality of OSS and PS is the same. We define $\Delta = V_{OS} - V_{PS} \geq 0$.In the remainder of the paper, we suppose that V_{OS} and V_{PS} are sufficiently large to ensure that the market is fully covered.

We assume also that there is a cost or disutility for installing and deploying OSS. This cost negatively depends on the user's' level of expertise. Users' skills θ are uniformly distributed on $(0, 1)$: for high skilled users, θ is close to 0 and for low skilled users θ is close to 1. For a given level of expertise θ, the disutility for installing OSS is equal to $c\theta$ whereas there is no disutility from deploying a PS (since PS is usually characterized by a user-friendly interface and technical support[6]). For high skilled user, OSS appears to be a better alternative; however, this may not be the case for low skilled users (even when the OSS has superior intrinsic quality).[7]

[5]Our model is close to the model in Comino and Manenti (2003). However, their assumptions related to software quality and compatibility are more restrictive. They consider that the two types of software are of the same quality, and are incompatible. They also assume that there is no cost or disutility from adopting OSS.

[6]PS is more user friendly than OSS because OSS is developed by highly skilled programmers who are also the potential users of this software. E.g., the installation of OSS requires downloading of source code, linking of libraries, setting environment variables for the operating system, and compelling the source code. Installation of most PS requires just a few clicks, and is backed up by technical support.

[7]The OS literature generally distinguishes two kinds of software quality: (1) usability (ease of installation, user interface, documentation, etc.) and (2) functional quality (reliability, maintainability, security, etc.). In our model, V_{OS} and V_{PS} refer to functional quality and c to the differential in usability. If we sum these two components ("usability" and "functional quality"), the OSS can be superior or inferior to the PS depending on whether the user is an expert or a novice.

For simplicity, the mass of users is equal to 1, and users adopt only one type of software (no multi-homing). User utility increases with the (intrinsic) quality of the software and the magnitude of the network effects. In the line with Katz and Shapiro (1985) and Shy (2001), we assume that the value of network externalities is γ times the number of users who have adopted the same or a compatible software (i.e. network size)[8]. As network size increases, it becomes easier to share or exchange data and files and get support. Since the number of software users is only known after the adoption choice, users have to form expectations about the respective numbers of OSS and PS users. We suppose that each user correctly anticipates the size of each software network (self-fulfilling beliefs).

We distinguish four situations, depending on whether the PS and the OSS are fully (two-way) compatible, partially (one-way) compatible or incompatible:

- Full incompatibility: the value of network externality for PS users is γN_{PS} (with N_{PS} the number of users who have adopted the PS) and the value of network externality for OSS users is γN_{OS} (with N_{OS} the number of users who have adopted the OSS);

- Full compatibility: the value of network externality for both users of OSS and PS is[9] $\gamma\left(N_{OS}+N_{PS}\right)=\gamma$;

- OSS-compatibility: if OSS is unilaterally compatible, PS users can access the OSS community, but OSS users cannot get any utility from the network of PS users. In this case, the value of network externality for PS users is $\gamma\left(N_{OS}+N_{PS}\right)=\gamma$, and the value of network externality for OSS users is γN_{OS};

- PS-compatibility[10]: if PS is unilaterally compatible, only OSS users can access PS users, and network externality value for OSS users and PS users is respectively $\gamma\left(N_{OS}+N_{PS}\right)=\gamma$, and γN_{PS}.

For the simplicity, let II and CC denote the full incompatibility and full compatibility regimes. Similarly, CI and IC represent the OSS-compatibility and PS-compatibility regimes.

The utility of type θ user under the different compatibility regimes is given by $U_\theta = V_{PS}+\gamma N_{PS}-p$ if the user buys a PS that is OS-incompatible, $U_\theta = V_{OS}+\gamma N_{OS}-c\theta$ if the user downloads an OSS that is PS-incompatible, $U_\theta = V_{PS}+\gamma-p$ if the user buys a PS that is OS-compatible and $U_\theta = V_{OS}+\gamma-c\theta$ if the user downloads an OS that is PS-compatible.

Assuming that the marginal cost of a PS is constant and normalized to zero, the profit of the software firm is given by:

$$\Pi^k = p^k N_{PS}^k \quad \text{with } k = II, CC, CI, IC$$

By definition, the open source community has no revenue (i.e. profit equal to zero)[11].

[8] Following Farrell and Saloner (1992), the value of network externality γ is supposed to be the same for both types of software.

[9] As the market is fully covered and the total number of users is 1, we have $N_{OS}+N_{PS}=1$.

[10] This case is less realistic since unilateral compatibility from PS to OSS is seldom observed.

[11] OSS is developed by open source communities whose members voluntarily contribute (during their working hours or free time).

In this paper, we analyze the impact of subsidies directed to OSS users. These subsidies can take the form of technical support or training to reduce the cost of adoption of OSS. Let s be the amount of subsidies per user and $S = sN_{OS}$ be the total cost of subsidizing OSS users. What should be the optimal level of subsidies? We assume that government's objective is to maximize the users' and producers' surplus net of the subsidy. However, we suppose that government places more weight on the users' surplus than on the software company's surplus. The relative weight of the producer surplus is given by α with $\alpha \in [0, 1]$. If $\alpha = 0$, the government only takes account of the users' surplus, and if $\alpha = 1$, government maximizes standard total welfare. There are two arguments that explain why government underweights the producer's surplus. First, since many software companies operate abroad, not all the profits of these foreign companies become part of the domestic social surplus[12]. Second, in matters of market regulation and competition policy issues, protection of users' interests is generally prioritized by government.

Consequently, government will choose the optimal amount of subsidy s that maximizes the weighted social surplus net of the cost of the subsidy[13]

$$W^k = \alpha\Pi^k + US^k - S^k \quad \text{with} \quad k = II, CC, CI, IC \;\; \text{and } \alpha \in [0, 1]$$

The timing of the model is as follows. In the first stage, government announces its OSS users policy. In the second stage, the firm sets the price of its software and users choose to adopt either the PS or the OSS. Throughout the paper, we restrict our attention to equilibrium outcomes in which both software products are used. The necessary conditions for the existence of an active duopoly is given by the following assumption.

Assumption 1. $c > \Delta + \gamma$ and $\Delta > \gamma$

This assumption holds if the adoption cost of OSS is sufficiently large, and PS and OSS are sufficiently differentiated in quality. Under **Assumption 1,** the software company has a positive market share regardless of compatibility regime[14].

3. Equilibrium outcomes

We start by solving the second stage of our model in which the proprietary firm sets its price and the users make their adoption decisions according to the four compatibility regimes.

3.1. Price and market shares

3.1.1. Incompatibility

When OSS and PS are mutually incompatible, the values of the network externalities for users of OSS and PS are respectively γN_{OS}, and γN_{PS}. Let $\widehat{\theta}^{II}$ be the marginal user who is indifferent between adopting PS and OSS. The solution is $\widehat{\theta}^{II} = \frac{(p+s-\gamma+\Delta)}{c-2\gamma}$: users with a type $\theta < \widehat{\theta}^{II}$ (high skilled) will prefer OSS and users with $\theta > \widehat{\theta}$ will adopt PS. It implies that the respective market shares of the OS community and the software

[12]Since the main PS companies are US firms, many European and Asian governments want to encourage adoption of OSS, especially for public administrations and schools (e.g. the Chinese government' support for Redflag, a local version of Linux.

[13]We assume that the full cost of the subsidy is borne by society through a lump sum tax.

[14]The more stringent condition required for an active duopoly relates to the incompatibility regime.

company are $N_{OS}^{II} = \widehat{\theta}^{II}$ and $N_{PS}^{II} = 1 - \widehat{\theta}^{II}$. The profit function of the software company is $\Pi^{II} = \frac{p(c-p-s-\Delta-\gamma)}{c-2\gamma}$ and its profit-maximizing price is equal to $p^{II}(s) = \frac{c-s-\gamma-\Delta}{2}$.

We observe that the price decreases with the amount of subsidy per user. The effect of the subsidy is to increase competition between the two types of software and reduce the market power of the software firm. After rearrangement, the market shares are $N_{OS}^{II}(s) = \frac{c+s-3\gamma+\Delta}{2(c-2\gamma)}$ and $N_{PS}^{II}(s) = \frac{c-s-\gamma-\Delta}{2(c-2\gamma)}$. Market shares are both positive if $c > 2\gamma$ and $c > s + \gamma + \Delta$.

3.1.2 Full (Two-way) Compatibility

When OSS and PS are fully compatible, the value of network externalities is γ regardless of the choice of software. Let $\widehat{\theta}^{CC} = \frac{(p+s+\Delta)}{c}$ be the user who is indifferent between downloading the OSS and buying the PS. The market shares of the OS community and the firm are given respectively by $N_{OS}^{CC} = \widehat{\theta}^{CC}$ and $N_{PS}^{CC} = 1 - \widehat{\theta}^{CC}$. Given the amount of the subsidy, s, the profit-maximizing price is equal to $p^{CC}(s) = \frac{c-s-\Delta}{2}$ and the equilibrium market shares are $N_{OS}^{CC}(s) = \frac{c+s+\Delta}{2c}$ and $N_{PS}^{CC}(s) = \frac{c-s-\Delta}{2c}$. The condition for an active duopoly is $c > \Delta + s$.

3.1.3 OSS compatibility

In this situation, PS users can access the community of OSS users, but the reverse is not possible. Then, the values of network externalities are γN_{OS} for an OSS user and γ for a PS user. Let $\widehat{\theta}^{CI} = \frac{p+s-\gamma+\Delta}{c-\gamma}$.be the user that is indifferent between PS and OSS. Then the optimal price for the software company is $p^{CI}(s) = \frac{c-s-\Delta}{2}$ and the equilibrium market shares are $N_{OS}^{CI}(s) = \frac{(c+s-2\gamma+\Delta)}{2(c-\gamma)}$ and $N_{PS}^{CI}(s) = \frac{c-s-\Delta}{2(c-\gamma)}$. OSS and PS have positive markets shares if $c > \gamma$ and $c > s + \Delta$.

3.1.4. PS compatibility

The last (but probably least realistic) scenario is a PS compatibility regime in which OSS users can unilaterally access the customer base of the PS. Thus, the value of the network externalities are γ for an OSS user and γN_{PS} for a PS user. Let $\widehat{\theta}^{IC} = \frac{(p+s+\Delta)}{c-\gamma}$. be the user indifferent between PS and OSS. The profit-maximizing price for the PS is given by $p^{IC}(s) = \frac{c-s-\gamma-\Delta}{2}$ and the equilibrium market shares are $N_{OS}^{IC}(s) = \frac{c+s-\gamma+\Delta}{2(c-\gamma)}$ and $N_{PS}^{IC}(s) = \frac{c-s-\gamma-\Delta}{2(c-\gamma)}$ OSS and PS have positive markets shares if $c > \gamma$ and $c > s + \gamma + \Delta$.

3.2. Optimal subsidies

Now, we turn to the first stage where government has to choose the opimal subsidy policy under each of the compatibility regimes. Its objective is to maximize the following function:

$$W^k = \alpha \Pi^k + \int_0^{\widehat{\theta}^k} \left(V_{OS} + \gamma \overline{N}_{OS}^k - \theta c + s^k \right) d\theta + \int_{\widehat{\theta}^k}^1 \left(V_{PS} + \gamma \overline{N}_{PS}^k - p^k \right) d\theta - S^k$$

where $\overline{N}_{OS}^{k}$ is the number of users that use the OSS or a software that is compatible with OSS, and $\overline{N}_{PS}^{k}$ is the network size of PS users or users of software compatible with the PS.[15] Remember that $k = II, CC, CI, IC$ and $\alpha \in [0,1]$.

The next proposition characterizes the optimal subsidy policy as a function of α (the weight that is placed on the software company's profit).

Proposition 1 *Under Assumption 1, the optimal policy is to subsidize OSS users if* $\alpha < 0.5$ *and the subsidies under the four compatibility regimes are given by*[16]

$$s^{CC*} = \frac{c-\Delta-2c\alpha+2\Delta\alpha}{3-2\alpha}\ ;\ s^{CI*} = \frac{c-\Delta-2c\alpha+2\Delta\alpha}{3-2\alpha}\ ;\ s^{IC*} = \frac{(1-2\alpha)(c-\Delta-\gamma)}{3-2\alpha}\ ;\ s^{II*} = \frac{(1-2\alpha)(c-\Delta-\gamma)}{3-2\alpha}$$

Subsidizing OSS reduces welfare if government puts too much weight on the software company's surplus (if $\alpha \geq 0.5$). This result is in line with the literature (e.g. Schmidt and Schnitzer, 2003; Comino and Manenti, 2005). When government's objective is to maximize the sum of users' surplus and firm's profit, the best policy - regardless of the compatibility regime - is "laissez-faire" or "technology neutral". In other words, government should never intervene to sponsor a technology but should let the market choose the best technologies.

However, if government places less weight on the producer's' surplus ($\alpha < 0.5$), then subsidy becomes welfare-enhancing. Logically, subsidy per user increases with the cost of OSS adoption (c) and decreases with the quality advantage of the OS product (Δ) and the weight that government puts on the software company's surplus. Note that network effects (γ) negatively influence the optimal level of subsidies only under the incompatibility and PS compatibility regimes. In these two situations, subsidies favoring OSS are less desirable because converting some PS users to the OSS doesn't increase the network externalities for OSS users (network effects are maximal and equal to γ), but does reduce network externalities for the remaining PS users (network effects are equal to γN_{PS}^{k}). In contrast, if subsidizing pushes some PS users to switch to OSS community, the network externalities are unchanged under full compatibility or OS compatibility. This explains why, under these two regimes, subsidies are independent of the magnitude of network effects.

Table 1 presents the equilibrium price, market shares, and profits if government subsidizes OSS users (under $\alpha < \frac{1}{2}$)

Table I: Equilibrium outcomes under the four compatibility regimes with $\alpha < \frac{1}{2}$

	II	CC	CI	IC
p^*	$\frac{(c-\Delta-\gamma)}{3-2\alpha}$	$\frac{c-\Delta}{3-2\alpha}$	$\frac{c-\Delta}{3-2\alpha}$	$\frac{(c-\Delta-\gamma)}{3-2\alpha}$
N_{PS}^*	$\frac{(c-\Delta-\gamma)}{(3-2\alpha)(c-2\gamma)}$	$\frac{(c-\Delta)}{3c-2c\alpha}$	$\frac{c-\Delta}{(3-2\alpha)(c-\gamma)}$	$\frac{c-\Delta-\gamma}{(3-2\alpha)(c-\gamma)}$
Π^*	$\frac{(\Delta-c+\gamma)^2}{(c-2\gamma)(2\alpha-3)^2}$	$\frac{(c-\Delta)^2}{c(2\alpha-3)^2}$	$\frac{(c-\Delta)^2}{(2\alpha-3)^2(c-\gamma)}$	$\frac{(\Delta-c+\gamma)^2}{(c-\gamma)(2\alpha-3)^2}$

We observe that the firm's profit, price, and market share increase with the cost of installing OSS (c) and decrease with the differential in quality (Δ), regardless of the

[15] $\overline{N}_{OS}^{k} = 1$ under the full compatibility and PS compatibility regimes and $\overline{N}_{OS}^{k} = N_{OS}^{k}$ under the incompatibility and OSS compatibility regimes.

Similarly $\overline{N}_{PS}^{k} = 1$ under the full compatibility and OSS compatibility regimes and $\overline{N}_{PS}^{k} = N_{PS}^{k}$ under the incompatibility and PS compatibility regimes.

[16] In each compatibility regime, the optimal subsidy is unique as $\frac{\partial^2 W^k}{\partial s^{k2}} < 0$ for $c > \Delta + \gamma$ and $\Delta > \gamma$.

compatibility regime. However, the role of network externalities differs under the four regimes. They have no impact on market shares and profits under full compatibility but increase the firm's profitability under OS-compatibility and decrease profits under full incompatibility and PS-compatibility.

The following subsection provides a comparative statics analysis of the equilibrium outcomes and subsidy policy across the four compatibility regimes. This analysis gives some insights into the desirability of public efforts to promote OSS.

3.3. Comparison of subsidies, public deficits, market shares, prices and profits

First, we compare the optimal amount of subsidy under the four compatibility regimes:

Proposition 2 *Under Assumption 1 and $\alpha < \frac{1}{2}$, the optimal subsidies per OSS user are characterized by* $s^{CC*} = s^{CI*} > s^{IC*} = s^{II*} > 0$

Proof. See **Proposition 1**. ■

Government gives a larger subsidy per user under the of two-way compatibility and OSS compatibility regimes. This result is quite intuitive. When OSS is compatible for PS users (CC or CI regimes), then subsidies will stimulate network effects within the OSS community (by increasing the number of OSS users), while the network effects for the PS users remain unchanged (equal to γ). This is not the case under full incompatibility and PS compatibility where subsidies reduce network externalities for the remaining PS users. Clearly government has a greater incentive to subsidize OSS users in the CC and CI situation since the returns in terms of welfare will be larger.

Proposition 3 compares the software company's price, market share, and profit under the four compatibility situations.

Proposition 3 *Under Assumption 1 and $\alpha < \frac{1}{2}$, given the optimal subsidies in each compatibility regime, then*

(*i*) $p^{CC*}\big|_{s=s^{CC*}} = p^{CI*}\big|_{s=s^{CI*}} > p^{IC*}\big|_{s=s^{IC*}} = p^{II*}\big|_{s=s^{II*}}$;
(*ii*) $N_{PS}^{II*}\big|_{s=s^{II*}} > N_{PS}^{CI*}\big|_{s=s^{CI*}} > N_{PS}^{CC*}\big|_{s=s^{CC*}} > N_{PS}^{IC*}\big|_{s=s^{IC*}}$;
(*ii*) $\Pi^{II*}\big|_{s=s^{II*}} > \Pi^{CI*}\big|_{s=s^{CI*}} > \Pi^{CC*}\big|_{s=s^{CC*}} > \Pi^{IC*}\big|_{s=s^{IC*}}$.

Proof. See **Table I** ■

The price of the PS is higher if PS users can access the OS community and benefit from network externalities from OSS users (CC or CI regime). In this case, consumers are willing to pay more for the PS and the software company can take advantage of this to increase its price. However, the ranking of the four regimes is different for profitability. The firm is better under full incompatibility: it enjoys a larger market share (since its price is lower) which translates into higher profits. The second best situation is OS-compatibility (CI) in which users are charged a higher price for the PS and receive a higher subsidy for the OSS compared to the full incompatibility case. The result is a lower market share and smaller profit for the software company than under full incompatibility. The worst (in terms of market share and profit) situation for the software firm is PS compatibility because consumers derive more utility from adopting OSS. The firm has to be more aggressive in its pricing. But it is not sufficient to retain its consumers given the subsidies distributed by the government.

The situation of full compatibility is between the OS and PS compatibility cases. The price of the PS (and the subsidy per OSS user) under full compatibility is the same as under OS-compatibility but the market share is lower because the firm has no exclusive advantage in terms of network externality under full compatibility. Its product is less attractive than under PS compatibility. This implies that if the PS firm has the possibility to choose among compatibility regimes, it will deny access to its customer base (by making its software incompatible for OSS users) .

Finally, Proposition 4 compares the fiscal burden of these subsidies (the fiscal burden calculations are given in the Appendix).

Proposition 4 *Under Assumption 1 and $\alpha < \frac{1}{2}$, the total costs of subsidizing OSS under the four compatibility regimes are characterized by $S^{CC*} > S^{CI*} > S^{IC*} > S^{II*}$*

Proof. See **Appendix.** ■

Subsidizing OSS is more costly when PS and OSS are fully compatible because of the large number of beneficiaries. Many users switch from PS to OSS as a result of a more generous subsidy policy. Full incompatibility is the least costly situation for government since the subsidy per user is lower than in the CC and CI regimes, and the number of beneficiaries is limited.

3.4 Comparison of Welfare Levels

Finally, we compare the weighted social welfare under the four regimes of compatibility.

Proposition 5 *Under Assumption 1 and $\alpha < \frac{1}{2}$, the optimal values of social welfare are characterized by*

$$W^{CC*}\big|_{s=s^{CC*}} > W^{IC*}\big|_{s=s^{IC*}} > W^{CI*}\big|_{s=s^{CI*}} > W^{II*}\big|_{s=s^{II*}}$$

Proof. See **Appendix .** ■

Government intervention in favor of OSS increases the weighted social welfare as long as $\alpha < \frac{1}{2}$. Regardless of the compatibility regime, the impact of a subsidy is to stimulate competition and push down the price of the PS, which increases user surplus more than it reduces producer surplus (since there is more weight on the former). However, the welfare impact of subsidies is larger if PS and OSS are mutually compatible since subsidizing OSS increases the reach of the high quality software (quality effects). The worst situation in terms of welfare is full incompatibility. Although subsidies may intensify competition, the users' surplus is lower since network externalities are limited (intra-network). The intermediate situation is the one-way compatibility regime with PS compatibility out-ranking OSS compatibility. When OSS users benefit from unilateral network effects (PS compatibility), consumers are more likely to adopt the OSS that offers superior quality and extended network externality. Subsidies can reinforce the attraction of OSS and the utility of OSS users (through quality and network effects).

5. Concluding remarks

Although there is an extensive OS literature focusing on the the issue of competition between PS and OSS, less attention has been paid to the role of public policy to promote OSS. This paper studied the impact of public subsidies for OSS users in the presence of network effects, and under different compatibility regimes.

Our main findings are that public subsidies push down the price of PS, increase the market share of the OSS and may stimulate network externalities when PS and OSS are partially incompatible (PS compatibility). If government puts sufficient weight on users' surplus, subsidizing OSS users is socially desirable. However, the optimal policy would be to provide larger subsidies per user under full compatibility and OSS (one-way) compatibility than, under full incompatibility and PS (one-way) compatibility.

Our theoretical model has several limitations and possible extensions. First, we consider that the quality of OSS and PS is exogenous. It would be interesting to add a stage that allowed the OS community and the software company to invest in the quality of their software. In this setting, subsidies for OSS users might discourage the PS firm from investing, and slow the pace of innovation. In addition, the choice of compatibility could also be endogenized. Our results suggest that the software company has strong incentives to make its product incompatible with the OSS. Another limitation of our model is that it is static and does not allow for inter-temporal pricing strategies. Future work could consider two periods and two generations of potential users. In the initial period, the software company could be more aggressive in order to achieve a critical mass of users and obtain competitive advantage (through network externality) in the second period. In this dynamic setting, optimal public subsidies could clearly differ over time.

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Appendix

Proof of proposition 4

As $S^{CC*} = \frac{(c-\Delta)(2c+\Delta)}{9c}$, $S^{CI*} = \frac{(c-\Delta)(2c-3\gamma+\Delta)}{9(c-\gamma)}$, $S^{IC*} = \frac{(c-\gamma-\Delta)(2c-2\gamma+\Delta)}{9(c-\gamma)}$ and $S^{II*} = \frac{(c-\gamma-\Delta)(2c-5\gamma+\Delta)}{9(c-2\gamma)}$, it can be shown that $S^{CC*} > S^{CI*} > S^{IC*} > S^{II*}$. Indeed, under **Assumption 1,** $S^{CC*} - S^{CI*} = \frac{1}{9c}\gamma\frac{(c-\Delta)^2}{c-\gamma} > 0$, $S^{CI*} - S^{IC*} = \frac{1}{9}\frac{\gamma}{c-\gamma}(c+2\Delta-2\gamma) > 0$ and $S^{IC*} - S^{II*} = \frac{1}{9}\frac{\gamma(\Delta-c+\gamma)^2}{c(c-3\gamma)+2\gamma^2} > 0$

Proof of proposition 5

When the government subsidizes the OSS users ($\alpha < \frac{1}{2}$), the weighted social welfare under the four compatibility regimes is given by

$$W^{*II} = \frac{\left(\begin{array}{c} c\Delta + 7c\gamma + \Delta^2 - 5\gamma^2 - \Delta\gamma + 2c^2\alpha + 3c(V_{OS}+V_{PS}) + 4\alpha\gamma^2 - 9\gamma V_{OS} \\ -3\gamma V_{PS} - 2c^2 + 6\alpha\gamma V_{OS} + 2\alpha\gamma V_{PS} - 2c\Delta\alpha - 6c\alpha\gamma + 2\Delta\alpha\gamma - 2c\alpha(V_{OS}+V_{PS}) \end{array}\right)}{2(3-2\alpha)(c-2\gamma)} \tag{A.1}$$

$$W^{*CC} = \frac{(c\Delta + 6c\gamma + \Delta^2 + 2c^2\alpha + 3c(V_{OS}+V_{PS}) - 2c^2 - 2c\Delta\alpha - 4c\alpha\gamma - 2c\alpha(V_{OS}+V_{PS}))}{2c(3-2\alpha)} \tag{A.2}$$

$$W^{*CI} = \frac{\left(\begin{array}{c} c\Delta + 6c\gamma + \Delta^2 - 3\gamma^2 + 2c^2\alpha + 3c(V_{OS}+V_{PS}) + 2\alpha\gamma^2 \\ -6\gamma V_{OS} - 2c^2 + 4\alpha\gamma V_{OS} - 2c\Delta\alpha - 4c\alpha\gamma - 2c\alpha(V_{OS}+V_{PS}) \end{array}\right)}{2(3-2\alpha)(c-\gamma)} \tag{A.3}$$

$$W^{*IC} = \frac{\left(\begin{array}{c} \Delta^2 - 7c\gamma + 5\gamma^2 - 2c^2\alpha - 4cV_{OS} - 2cV_{PS} - 4\alpha\gamma^2 - 2\Delta V_{OS} \\ +2\Delta V_{PS} + 4\gamma V_{OS} + 2\gamma V_{PS} + 2c^2 - 4\alpha\gamma V_{OS} + 6c\alpha\gamma + 4c\alpha V_{OS} \end{array}\right)}{2(2\alpha-3)(c-\gamma)} \tag{A.4}$$

After calculations, we obtain the four social welfare functions are ordered as follows: $W^{CC*}\big|_{s=s^{CC*}} > W^{IC*}\big|_{s=s^{IC*}} > W^{CI*}\big|_{s=s^{CI*}} > W^{II*}\big|_{s=s^{II*}}$ [17]

[17] Calculations are available upon request.