Open Source Software, Closed Source Software or Both: Impacts on Growth in the Context of Intellectual Property Rights, Spillovers and Innovation*

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Abstract

The information economy has required existing intellectual property law (IPL) to adapt itself to new forms of information goods. Software is one such information good around which there is considerable debate regarding intellectual property rights (IPRs). In our model we examine the co-existence of open and closed source software in the context of spillovers within varying IPR structures ranging from no protection, copyright to patent protection. Our results confirm that a co-existence exists between open and closed source software can be growth optimal. Further, we find that it is not important if the ability to benefit from the other sector's spillovers is equal, only the sum of the interdependent parts of productivity growth is important. Finally, we observe that the move from no protection to copyright protection increases the optimal growth rate and makes both open and closed software sectors better off. However, the benefits of moving from copyright to patent protection is less clear.

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1 Introduction

The information economy has required existing intellectual property law (IPL) to adapt itself to new forms of information goods. Software is one such information goods around which there is considerable debate regarding intellectual property rights (IPRs). In an industry, traditionally protected by copyright, questions regarding the "proper role of copyright" (Baseman et al. 1994) and the "economic impacts and policy implications" (Blind et al. 2005) of software patents are being extensively debated. The software industry has seen the emergence of two different types of technology sharing strategies (Jansen 2006).

Broadly seen, the software industry can be divided in to proprietary and open source software (OSS). The main difference between the two lies in the provision of the source code: Proprietary software is typically sold only as binary code where access to the source code is prohibited.footnoteBinary code refers to the version of software that is only machine-readable while the source code refers to the human readable version of a computer program. Alternatively, when the source code is "open" and information is disclosed, the software is termed OSS.[1] The former mode of distribution prevents competitors from reproducing their software. The latter allows all users to have access to the source code, the right to read, modify, redistribute and use the software. In this context, one could refer to OSS as "private provision of a public good" (Johnson 2002).

Several economists have concentrated on each of the two sectors individually: Monopoly structures have been studied in a static setting in order to explain Microsoft's various strategies and behavior (Gilbert & Katz 2001, Whinston 2001, Klein 2001). Other articles examine the OSS sector in terms of motivation, output, structure and the various licenses (Maurer & Scotchmer 2006, Lerner & Tirole 2002, von Hippel 2005).

From a theoretical point of view, IPRs are designed to create incentives to the innovator (ex-ante incentive) and to ensure that information is disclosed within the public domain (ex post efficiency). Very often, technical improvements in software are not new ideas but new expressions of an idea. Copyright protects the expression of an idea. With regard to software, it prevents direct copying but allows the copying of the underlying idea and concept. This allows market entry for those innovators who manufacture similar or complementary products i.e. product differentiation. Yet despite the seemingly modest nature of copyright, it has taken on much more significance in the case of software

[1] OSS is developed by communities including a broad range of participants from hobbyists to companies like IBM, HP, Sun Microsystems and OSS distributors like Red Hat or Novell's SuSE.

particularly in the context of strong network effects conferring a great deal of market power e.g. Microsoft. Thus, the scope of copyright protection (Baseman et al. 1994) can have significant implications for competition and innovation.

In 1981, as a result of the Diamond vs. Diehr case, patent protection was extended to software[2] in the United States. It was decreed that algorithms qualified for patent protection as the distinction between abstract and physical was not clear (Merges 1999). Patents do not protect the underlying ideas of an innovation but they protect the invention i.e. the new technical application of an idea. They are awarded to software innovations for originality, novelty, and non-obviousness in exchange for early disclosure of the innovation to society. The merits of patent protection have been argued against by several economists and lawyers (Samuelson 1990, Bessen & Maskin 2000, Maurer & Scotchmer 2002, Gallini 2002, Lessig 2005). Bessen & Maskin (2000) empirically showed that instead of increased innovative growth, patents in the software industry actually resulted in decreasing R&D activity by limiting the cumulative innovation process. The theoretical literature suggests that if R&D is cumulative and sequential, then excessive protection impedes rather than promotes future innovation (Merges & Nelson 1990, Scotchmer 1991).

We build our paper based on the idea that the co-existence between OSS and proprietary software is beneficial to innovative growth within the software industry. In order to address this, we make use of the spillover concept. Innovations in application software or operating systems are often sequential, complementary (Bessen & Maskin 2000) and cumulative (Friedewald et al. 2002) where improvements are characterized as new expressions of existing knowledge. Thus, knowledge spillovers from rivals actually contribute to private investment and spur further technical advancement (Arrow 1962, Jaffe 1986). We take this a step further and suggest that the amount of spillover activity taking place is a direct consequence of the IPR regime in place. In order to be able to benefit from incoming spillovers, firms need to increase their "absorptive capacity" (Cassiman & Veugelers 2002).

When utilizing the spillover concept, the two broad OSS licenses need to be considered; *public* and *viral* licenses. All licenses within the OSS domain are governed by copyright laws as is the case with proprietary software[3]. The important difference between the two is that while OSS licenses *include*, non-OSS licenses *exclude*. Copyright is used (together with technical facilities i.e.

[2]For the purpose of our study, we confine ourselves to pure software patents and do not consider business method patents.

[3]It is often "misperceived [that OSS] remove[s] copyright protection. It is based on copyright principles." (Gehring 2006, p 62, 70) The term 'proprietary' comes from the Latin term 'proprietarius' and its legal meaning is protected by copyrights.

copy protection) to prevent the disclosure of information. Thus, some observers – and we will follow this consideration – refer to proprietary software as closed source software (CSS).

Public licenses, like the Berkeley Software Distribution (BSD) license, do not restrict the use of the software or the source in any way. This means that software under such a license can not only be re-used and re-combined, but also redistributed under any preferred license, regardless of whether the code is changed and/or combined with other code or not. *Viral* licenses like the General Public License (GPL) differ in terms of alienation rights as the right to distribute is restricted. This means that any software where (part of) viral OSS is included becomes OSS as well. Thus, the license is viral as it infects any program code it is combined with but only if and as soon as the 'new' software is distributed. Thus, one can interpret OSS licenses as being a contract to all, offering all users the whole set of rights, while the possible constraints are only relevant upon redistribution.

In our model, we develop a model where we examine the co-existence of OSS and CSS in the context of spillovers within varying IPR regimes. Section 2 describes the model set-up followed by section 3 which specifically examines differing IPR scenarios, namely; no protection, copyright protection and patent protection. We conclude with section 4.

2 The model

We consider an economy consisting of one industry only. This industry—the software industry—has two sectors, A and B, with A represents the OSS sector and B represents the CSS sector.

Let F be the total input stock available to produce the first copies of software. The part of F that is used to produce software of type A at time $t = T$ ("Today") is given by $\theta(T) \cdot F$, with $0 \leq \theta \leq 1$. Therefore $(1 - \theta(T)) \cdot F$ is used to produce software of type B. We assume, that the economy is in a stable equilibrium, thus $\theta(t)$ does not change over time given no change in exogenous defined parameters: $\theta(t) = \theta = f(\cdot)$, $\forall t$. Without loss of generality we normalize $F = 1$ so that the division of the given input stock is described by the value of θ.

We assume that the first-copy-production function for each sector (A or B) can be described with a simple linear function, i. e. the output is the result of the input multiplied with a productivity measure $p_A(t)$, $p_B(t)$ respectively: $Y_A(t) = p_A(t)\theta$ and $Y_B(t) = p_B(t)(1 - \theta)$. The productivity of sector A (B) is the product of a basic niveau-factor, denoted by a (b) and a spillover dependent part, denoted by $\sigma_A(t)$ ($\sigma_B(t)$), such that $p_A(t) = a(1 + \sigma_A(t))$ and $p_B(t) = b(1 + \sigma(t))$. Therefore, the total output of the industry at time T ('Today') is given by

$$\begin{aligned} Y(T) &= Y_A(T) + Y_B(T) = a(1 + \sigma_A(T))\theta + b(1 + \sigma_B(T))(1 - \theta) \quad (1) \\ \text{with} & \quad a, b, \sigma_A(T), \sigma_B(T) \geq 0 \end{aligned}$$

The spillover dependent part of productivity is determined by the sector's ability to benefit from the spillovers of each sector. The spillovers itself of one sector are approximated by the discounted cumulated input of this sector, given by $\int_0^T v(T,t) \cdot \theta \, dt$, and $\int_0^T v(T,t) \cdot (1 - \theta) \, dt$ respectively. Notice that $v(T,t)$ is a given discount function such that

$$1 \geq v(T,t) \geq 0 \, \forall t, \quad \lim_{(T-t)\to\infty} v(T,t) = 0, \quad \lim_{(T-t)\to 0} v(T,t) = 1 \tag{2}$$

and

$$g(T) = \frac{\partial \int_0^T v(T,t)}{\partial T} = \int_0^T \frac{\partial v(T,t)}{\partial T} dt + v(T,T) \leq 1. \tag{3}$$

In the general case, every sector can benefit from inter- and intra-sectoral spillovers. To indicate the inter- and intra-sectoral spillovers, we label the inter-sectoral spillover effect (the ability to benefit) of sector i on sector j with s^{ij} and similarly the intra-sectoral spillover effect of sector i with s^{ii} ($s^{ij}, s^{ii} \geq 0$). Thus, the spillover dependent part of productivity is described as follows:

$$\begin{aligned} \sigma_A(T) &= s^{AA} \int_0^T v(T,t)\theta dt + s^{BA} \int_0^T v(T,t)(1 - \theta) dt \\ \frac{d\sigma_A}{dt} &= s^{AA}\theta g(T) + s^{BA}(1 - \theta) g(T) \qquad (4) \\ \sigma_B(T) &= s^{BB} \int_0^T v(T,t)(1 - \theta) dt + s^{AB} \int_0^T v(T,t)\theta dt \\ \frac{d\sigma_B}{dt} &= s^{BB}(1 - \theta) g(T) + s^{BA}\theta g(T) \qquad (5) \end{aligned}$$

With (1), (4) and (5) it is easy to compute the growth of output ($\dot{Y} = dY/dt$).

As we want to know the division of F that yields maximum growth, we compute the optimal $\theta^\star$ that implies maximum $\dot{Y}$, thus our optimizing problem is given by:

$$\max_{\theta\in[0,1]} \dot{Y}(T) = g(T) \left(\theta^2 \cdot as^{AA} + (1 - \theta) bs^{BB} + \theta(1 - \theta)(as^{BA} + bs^{AB})\right) (6)$$

And the First order condition yields

$$\theta^\star = \frac{1}{2} \cdot \frac{(as^{BA} + bs^{AB}) - 2 \cdot bs^{BB}}{(as^{BA} + bs^{AB}) - as^{AA} - bs^{BB}} \tag{7}$$

for an interior solution, and $\theta^\star = 0$ or $\theta^\star = 1$ otherwise. The second order condition (SOC) of $\max_{\theta \in [0,1]} \dot{Y}$ yields

$$as^{AA} \leq (as^{BA} + bs^{AB}) - bs^{BB} \tag{8}$$

The boundary $\theta^\star \geq 0$ implies

$$bs^{BB} \leq \frac{1}{2}(as^{BA} + bs^{AB}), \tag{9}$$

and $\theta^\star \leq 1$ implies

$$as^{AA} \leq \frac{1}{2}(as^{BA} + bs^{AB}). \tag{10}$$

Thus, these two conditions imply that an interior solution always fulfills the SOC (8). Thus, only within the $\frac{1}{2}(as^{BA} + bs^{AB})$ boundaries a mixture of OSS and CSS is growth optimal. The mixed area increases, if either A's benefit resulting from the inter-sectoral spillovers (as^{BA}) or B's benefit from the inter-sectoral spillovers (bs^{AB}) increases, or both. It is important to note, that the apportionment of as^{BA} and bs^{AB} does not play a role, only the sum ($as^{BA} + bs^{AB}$) determines the area where $0 < \theta < 1$ is optimal. This result is similar to findings on network theory concerning adapters: Regarding a two-network case, Church & King (1993) showed, that if adapters are costly to install, then it is optimal to install only one adapter that enables one network to benefit from the other. This implies, if adapters are not costly, then there is at least no need to install two adapters, it is only essential that there is an exchange. Thus spillovers have analogies with network externalities, which is not really surprising.[4]

However, since $(as^{BA} + bs^{AB})$ is the sum of the parts of productivity growth that depends on inter-sectoral spillovers, we refer to it in the following as the

[4]The growth of a sector (A or B) increases with an increase in a) its own share of input (and therefore share of output, thus, market-share) and b) the other's sector share of input, as much as it can benefit from the other through inter-sectoral spillovers. If one now replaces the term 'growth' by 'utility', the term 'sector' by 'good', the term 'share of input' by 'installed base' and the term 'inter-sectoral spillovers' by 'adapter', we get the network adapter case: The utility of one good (A or B) increases with an increase in a) its own installed base and b) the other good's installed base, as much as it can benefit from the other's installed base by the adapter.

interdependent parts of productivity growth and denote it with γ, therefore $\gamma = (as^{BA} + bs^{AB})$. Additionally we will use $\alpha = as^{AA}$ and $\beta = bs^{BB}$ and call this the autonomous parts of productivity growth. This shortens the first order condition (7) to

$$\theta^{\star} = \frac{1}{2} \cdot \frac{\gamma - 2 \cdot \beta}{\gamma - \alpha - \beta} \tag{11}$$

and the boundaries (9) and (10) to

$$\beta \leq \frac{1}{2}\gamma, \tag{12}$$

$$\alpha \leq \frac{1}{2}\gamma.. \tag{13}$$

Figure 1: Share of Input (θ) for Maximum Growth

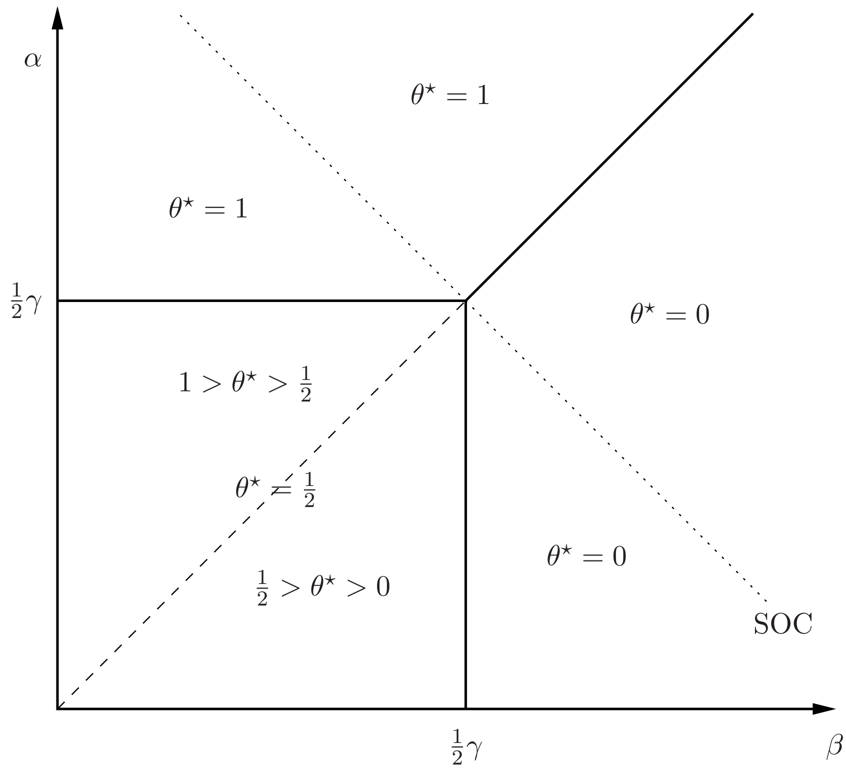


Figure 1 depicts (12) and (13), as well as (8). Additionally, figure 1 depicts $\alpha = \beta$ (i.e. $as^{AA} = bs^{BB}$) which implies $\theta^{\star} = \frac{1}{2}$. For any combination of α

and β where the second order condition is *not* fulfilled, $\theta^\star = 0$ if $\alpha < \beta$ (i.e. $as^{AA} < bs^{BB}$) and $\theta^\star = 1$ if $\alpha > \beta$ (i.e. $as^{AA} > bs^{BB}$).

Applying equation (11) or one of the boundary solutions—i. e. taking into account (12) and (13)—to (6) leads to $\dot{Y}^\star(T) = \dot{Y}(\theta^\star, T)$ given by

$$\dot{Y}^\star(T) = \dot{Y}(\theta^\star, T) = \begin{cases} \alpha \cdot g(T) & \text{if } \theta^\star = 1, \\ \beta \cdot g(T) & \text{if } \theta^\star = 0, \\ \frac{\gamma^2 - 4\alpha\beta}{4(\gamma-\alpha-\beta)} \cdot g(T) & \text{else.} \end{cases} \tag{14}$$

Furthermore,

$$\frac{\partial \dot{Y}^\star(T)}{\partial \alpha} = \begin{cases} \dfrac{(2\beta-\gamma)^2}{4\left(\alpha+\beta-\gamma\right)^2} \cdot g(T) > 0 & \text{if } \alpha, \beta < \dfrac{1}{2}\gamma, \\ g(T) > 0 & \text{else} \end{cases} \tag{15}$$

and

$$\frac{\partial \dot{Y}^\star(T)}{\partial \beta} = \begin{cases} \dfrac{(2\alpha-\gamma)^2}{4\left(\alpha+\beta-\gamma\right)^2} \cdot g(T) > 0 & \text{if } \alpha, \beta < \dfrac{1}{2}\gamma, \\ g(T) > 0 & \text{else} \end{cases} \tag{16}$$

as well as

$$\frac{\partial \dot{Y}^\star(T)}{\partial \gamma} = \begin{cases} \dfrac{(2\alpha-\gamma)(2\beta-\gamma)}{4\left(\alpha+\beta-\gamma\right)^2} \cdot g(T) > 0 & \text{if } \alpha, \beta < \dfrac{1}{2}\gamma, \\ 0 & \text{else} \end{cases}. \tag{17}$$

A simultaneous change of α, β and γ leads to a change of $\dot{Y}^\star(T)$ as given by the total derivative

$$d\dot{Y}^\star(T) = \frac{d\alpha(2\beta-\gamma)^2 + d\beta(2\alpha-\gamma)^2 + d\gamma(2\alpha-\gamma)(2\beta-\gamma)}{4\left(\alpha+\beta-\gamma\right)^2} \cdot g(T), \tag{18}$$

thus

$$d\dot{Y}^\star(T) > 0 \quad \forall\, d\alpha(2\beta-\gamma)^2 + d\beta(2\alpha-\gamma)^2 + d\gamma(2\alpha-\gamma)(2\beta-\gamma) > 0 \tag{19}$$

To sum up: For some parameter-combinations, an OSS-CSS-mixture is growth optimal. As the inter-sectoral spillovers have to some extend similarities with adapters in networks, only the *sum* of the interdependent parts of productivity growth is important.

3 Three possible intellectual property law regimes

Copyrights and patents are similar in that they grant the bearer right of use and the right to exclude others. Exclusion can be circumvented via license agreements. Within the CSS and OSS domains there are different licenses in operation which have varying impacts on spillover activity. The following three sections examine three cases: No protection, copyright and software patents.

3.1 No protection

CSS business models are based on the principle of exclusive control over intellectual property. If there is no IPL that CSS firms can rely upon, the only strategy they can pursue is to hide all their intellectual property in order to avoid any spillover activity. Therefore, in such a world, CSS would only be provided in binary code, protected through encryption (Gallini & Scotchmer 2001), or by using sophisticated technical copy protection minimizing spillover activity. Additionally, cooperation between CSS firms based upon the sharing of source code (e.g. common development of software parts) might not occur in the no protection case (or are at least not stable), as the lack of IPL provides no legal protection in the case of conflict. So s^{BB} and s^{BA} are virtually zero, and therefore we set $s^{BB} = s^{BA} = 0$ for this case.

With regard to the OSS case (sector A), the absence of IPR leads to only BSD like licenses. Thus, in this scenario, only A produces spillovers, from which both sectors benefit:. s^{AA} and s^{AB} are both positive, thus $s^{AA} > 0$ and $s^{AB} > 0$.

With $s^{AA} \geq 0,\ s^{BB} = 0,\ s^{AB} > 0$, and $s^{BA} = 0$, the expressions (8), (12), and (13) yield

$$\theta^{\star} = \begin{cases} \frac{1}{2} & \text{if} \quad \alpha = 0 \\ \frac{1}{2} \cdot \frac{\gamma}{\gamma - \alpha} & \text{if} \quad 0 < \alpha < \frac{1}{2}\gamma \\ 1 & \text{if} \quad 2\alpha \geq \frac{1}{2}\gamma \end{cases} \tag{20}$$

with $\gamma = (0 + bs^{AB}) = bs^{AB}$.

Some authors argue, that "the open-source development method must consequently be classified as neither economically efficient nor effective." (Kooths et al. 2003, p 64). However, *even if* the OSS sector has very low productivity levels, (i.e. a is virtually zero), a 50%-mixture of OSS and CSS is growth-optimal. As long as $\alpha < {}^1\!/_2 \cdot \gamma$, a mixture is growth optimal, with the optimal share of OSS increasing from 50% to 100% when α is increasing up to ${}^1\!/_2 \cdot \gamma$.

For all $\alpha \geq 1/2 \cdot \gamma$, an input-share of 100% of OSS is optimal. Let us, for argument's sake, assume that OSS might not be as productive as CSS i.e. $a < b$. However, considering the fact that BSD-like licenses enable both, CSS and OSS producers to use BSD-licensed source code (thus virtually $s^{AA} = s^{AB}$), it is at least not unlikely that $\alpha < 1/2 \cdot \gamma = 1/2 \cdot bs^{AB}$, $0 < bs^{AB}$ respectively.

Thus, we obtain that a mixture of OSS and CSS is growth optimal in the case of no IPL. In other words: regarding the figure 1, this situation would be indicated by a point at the α-axis, somewhat below the $1/2 \cdot \gamma$-frontier.

As we want to examine the impact of introducing copyright and software patents on the optimal input share, on the optimal growth respectively, we assume—without specifying the underlying micro-economic logic—the following:

Assumption 3.1. The realized θ always equals $\theta^\star$ given by (11).

3.2 Copyright

Copyright protection could be beneficial to the CSS sector (sector B) as it could have a positive effect on the spillover-independent part of productivity b because IPRs set positive incentives for CSS-producers by creating exclusion opportunities. Thus, with the change from no protection to copyright protection, the effect on b would be, at minimum, positive: $db > 0$.

In this scenario, inter-firm co-operations that would have been unstable in the case of no protection are now possible. Thus, contract based code sharing is now possible for CSS firms. Additionally, firms can now exclusively protect their software by legal arrangements and alternative measures. Therefore, hiding the source code is not as essential as before for CSS firms. To sum up, we assume, that by introducing copyright protection, the intra-sectoral spillovers of sector increase B: $ds^{BB} > 0$.

Regarding the inter-sectoral spillovers from sector B, the impact is at least non negative: Recall that we assumed before that $s^{BA} = 0$, thus the impact of introducing copyright protection can consequentially only be greater-than-or-equal to zero. Assuming that there is no need to hide 'almost everything' it is likely that with copyright-protection s^{BA} is positive, albeit small. This leads to $ds^{BA} \geq 0$.

Regarding the OSS sector, the introduction of copyright law means, that GPL-like licenses are now possible, and this should have a positive impact on the spillover independent productivity of sector A: In the long run, commercial OSS projects can survive only if market players that base their business model on the OSS movement participate in the OSS development process, thus financing (at least a part of) the OSS-developers. These firms engage in cost sharing and act like firms in an R&D venture but without explicit firm-to-firm contracts: the unique selling point of each firms' end product (e.g. its Linux distribution) is only what is added (parts of software and/or service) to the commonly developed part (Casadesus-Masanell & Ghemawat 2003). It is obvious, that if 'exploiting' (that is using the given OSS without giving something back to the OSS-development-pool) is the dominant strategy, then the cooperation equilibrium of this R&D game is unstable. As the BSD license is easier to exploit than the more restrictive GPL, we can argue as follows: A change from BSD to GPL increases the stability of such a R&D cooperation, thereby reducing the risk when participating in such a game which in turn reduces transaction costs for the OSS production mode (Weber 2004). This may be one of the reasons, why the GPL is the most successful OSS license (Ghosh 1998). A second aspect is the adding effect: if the GPL license results in new projects, it could mean that resources are currently being used, which were not used before. Taking this two effects together, introducing copyright leads to $da > 0$.

Concerning the intra-sectoral spillovers, one could argue, that it does not matter whether BSD or GPL like licenses exist, as the constraints of the GPL are important only for CSS-producers. But one could also argue, that more variety in licenses is likely to cause more spillovers, in particular if the new licenses strengthen "openness" more than the old ones - and the GPL strengthens "openness" more than the BSD. However, this means, that introducing copyright protection leads to $ds^{AA} \geq 0$.

With respect to the inter-sectoral spillovers from sector A, the introduction of copyright could have a negative effect because of what we call the "replacement effect": On the one hand, former BSD-projects may now turn in to GPL-protected (replacement effect), whereas on the other hand new projects may arise, that are GPL-protected and could not have been realized before (additive effect). As GPL-like licenses are "viral" in nature, GPL-protected source code can not be used to produce CSS, the adding effect is not important for s^{AB}. However, if there is a replacing effect, the CSS-sector can benefit less from the OSS-sector, because the percentage of projects CSS can benefit from, decreases. Therefore, as long as it is not specified whether there is a replacing effect or not, the impact of introducing copyright on s^{AB} is either negative or zero: $ds^{AB} \leq 0$.

Thus, the impacts on the parameters of introducing copyright law are:

$$\begin{array}{rcl} d\alpha = d[as^{AA}] &=& da \cdot s^{AA} + a \cdot ds^{AA} + da \cdot ds^{AA} & > & 0 \\ d\beta = d[bs^{BB}] &=& db \cdot s^{BB} + b \cdot ds^{BB} + db \cdot ds^{BB} & > & 0 \\ d[as^{BA}] &=& da \cdot s^{BA} + a \cdot ds^{BA} + da \cdot ds^{BA} & \geq & 0 \\ d[bs^{AB}] &=& db \cdot s^{AB} + b \cdot ds^{AB} + db \cdot ds^{AB} & \lesseqgtr & 0 \\ && \Rightarrow d\gamma = d[as^{BA} + bs^{AB}] & \lesseqgtr & 0 \end{array} \tag{21}$$

Therefore, introducing copyright *can* decrease of the sum of interdependent parts of productivity growth, this *can* yield a decrease of growth. But it is important to notice, that $d[as^{BA} + bs^{AB}] < 0$ is a necessary but *not sufficient* condition for $d\dot{Y}^\star < 0$. From (19) one derives the condition for $d\dot{Y}^\star(T) < 0$ given by $d\alpha(2\beta-\gamma)^2 + d\beta(2\alpha-\gamma)^2 < -d\gamma(2\alpha-\gamma)(2\beta-\gamma)$. Hence, a necessary, but not sufficient condition for $d\dot{Y}^\star < 0$ is that $-d\gamma > 2 \cdot \sqrt{d\alpha \cdot d\beta}$. For example, for $-d\gamma = d\beta = 1$ the necessary condition is fullfilled only if $d\alpha < 1/4$. To give an impression of the *sufficient* condition, for $d\dot{Y}^\star(T) < 0$ we present the following cases for $-d\gamma = d\beta = 1$ $(\alpha, \beta < 1/2\gamma)$:

$$\text{if } d\alpha = 0.25, \text{ then } d\dot{Y}^\star(T) \begin{cases} = 0 & \text{only if } \alpha = 0.25 + 0.5\beta \\ > 0 & \text{else} \end{cases} \tag{22}$$

$$\text{if } d\alpha = 0, \text{ then } d\dot{Y}^\star(T) \begin{cases} < 0 & \text{only if } \alpha > \beta \\ \geq 0 & \text{else} \end{cases} \tag{23}$$

To sum up: Introducing copyright reduces optimal growth *only if* the decrease of s^{AB} (caused by the replacement effect) overcompensates *all other effects*, i.e. *only* if

$$\frac{\partial \dot{Y}^\star}{\partial a} da + \frac{\partial \dot{Y}^\star}{\partial b} db + \frac{\partial \dot{Y}^\star}{\partial s^{AA}} ds^{AA} + \frac{\partial \dot{Y}^\star}{\partial s^{BB}} ds^{BB} + \frac{\partial \dot{Y}^\star}{\partial s^{BA}} < -\frac{\partial \dot{Y}^\star}{\partial s^{AB}} ds^{AB}, \tag{24}$$

which seems to be an unlikely case. Due to that we assume, that $d\dot{Y}^\star > 0$.

3.3 Patents

In the next step, we examine the impact of introducing software patents. Although the OSS sector does not actively use patents, it does not imply that software patents do not have an impact on the OSS sector. Software patents could lead to higher transaction costs for OSS developers due to the "patent thicket" (Shapiro 2003), as information (OS)S programmers use and want to use, may be patent protected. Thus, this induces information costs and/or uncertainty and risk, no only for OSS developers (For the discussion on software patents and the patent thicket problem see e.g. Mann (2005, 2004) vs. Bessen & Hunt (2004*b*), Bessen (2006)).

However: In the case of copyrighted software, though rights are ensured to the original author and expression, other innovators have access to the underlying idea. Though patents do not protect the idea either, they protect the commercial use of a particular idea. Software has practical use only when it is interoperable and when patents are introduced environment, subsequent innovation becomes a strategic power game. OSS tends to get locked out as it primarily operates on shared source code. Most developers are no longer willing to take the risk of litigation with the big CSS players and their patent portfolios.

This could yield a negative change on the independent part of productivity of OSS ($da < 0$). Some authors (e.g. Mann) argue that this information problem of (software) patents is overemphasized. One can imagine that e.g. a central online database of patented software could solve the information problem. In this case software patents would not affect the spillover independent part of OSS productivity: $da = 0$. However, we regard it more likely that the introduction of software patents would lead to a decrease of a, thus, $da < 0$.

As OSS developers do not use patents, no new licenses types emerge. Due to this, we assume no major change in s^{AA} and s^{AB}, neither in the ability of the OSS sector to benefit from spillovers from OSS sector, nor will the ability of the CSS sector to benefit from OSS spillovers be affected by the introduction of software patents: $ds^{AA} = ds^{AB} = 0$.

Patents have a different impact on CSS firms. Due to incentive arguments (Nordhaus 1969), it is reasonable to assume that the possibility to exploit (for a finite time period) a software invention exclusively would lead to $db > 0$. Even if one takes into account that patents may also increase transaction costs for CSS developers, then at least $db \geq 0$ is likely (Merges & Nelson 1990).

Software patent applications cannot contain complete information as this would mean revealing the source code. It could be argued that descriptions provided in patent applications could lead to positive spillovers. However, on the one hand, descriptions given in exchange for patent protection are often not clear and precise enough for it to be beneficial enough to others (Levin 1988, Cohen et al. 2002). Thus, this could result in a duplication of research efforts whereas in a setting with interdependent spillovers, wasteful expenditures on R&D could be reduced (Blind et al. 2005). On the other hand, spillovers do occur despite such protection through the trading and sharing of knowledge, labor mobility and possibility to reverse engineer. Crampes & Langinier (2005) found, that in order to prevent this, under certain conditions firms chose not to renew their patents to prevent information from entering the market. Without explicitly specifying the relationship between this positive amount of information and spillover effects, it is reasonable to assume a positive effect, thus, $ds^{BB} > 0$ and $ds^{BA} > 0$.

To sum up, the expected impact on the parameters of introducing software patents are:

$$\begin{array}{rcll} d\alpha = d[as^{AA}] & = & da \cdot s^{AA} + a \cdot ds^{AA} + da \cdot ds^{AA} & < 0 \\ d\beta = d[bs^{BB}] & = & db \cdot s^{BB} + b \cdot ds^{BB} + db \cdot ds^{BB} & > 0 \\ d[as^{BA}] & = & da \cdot s^{BA} + a \cdot ds^{BA} + da \cdot ds^{BA} & \lesseqgtr 0 \\ d[bs^{AB}] & = & db \cdot s^{AB} + b \cdot ds^{AB} + db \cdot ds^{AB} & > 0 \\ & & \Rightarrow d\gamma = d[as^{BA} + bs^{AB}] & \lesseqgtr 0 \end{array} \tag{25}$$

Due to $d\gamma \lesseqgtr 0$ we can identify three possible scenarios:

- $d\gamma = 0$, in this case, the impact of introducing software patents on $\dot{Y}^\star$ depends on the relative impact of $d\alpha$ and $d\beta$ only. Thus (19) simplifies to $d\dot{Y}^\star(T) > 0 \quad \forall \; d\alpha(2\beta - \gamma)^2 + d\beta(2\alpha - \gamma)^2 > 0$. Let us express the relative change of α and β with k, such that $d\alpha = -k \cdot d\beta$. This yields the following:

$$\forall \; d\alpha = -k \cdot d\beta, \; k > 0, \; d\beta > 0 \; : \; d\dot{Y}^\star \geq 0 \iff k \leq \frac{(2\alpha - \gamma)^2}{(2\beta - \gamma)^2} \tag{26}$$

Thus, for any given relative reverse change of α and β—i.e. for any given $k > 0$—it is possible to compute the area of (α, β)-combinations, where optimal growth rate *increases* because of $-d\alpha < k \cdot d\beta$, i.e. the decrease of α is overcompensated by the increase of β. Thus, for any given k^{max} one can compute boundaries where $d\dot{Y}^\star(k^{max}) = 0$ and hence $\forall k < k^{max}$ $d\dot{Y}^\star(k) > 0$:

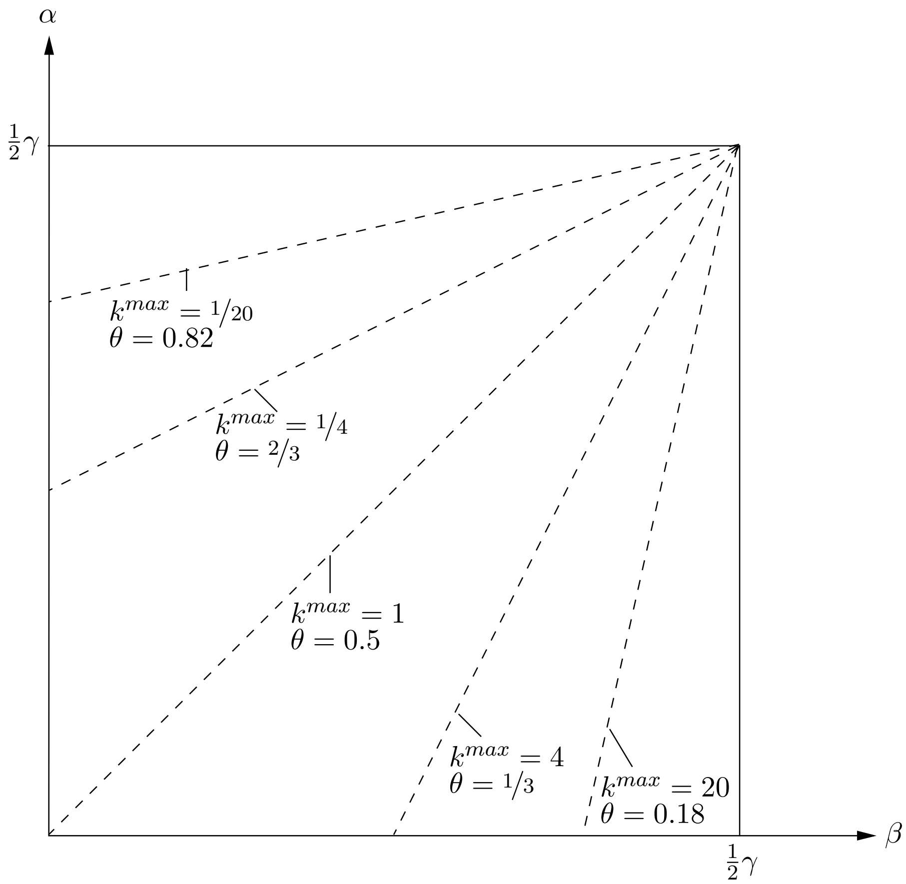
$$\alpha = \frac{1}{2}\gamma - \frac{1}{2}\sqrt{k^{max}(\gamma - 2\beta)^2}. \tag{27}$$

Using this to replace α in (11) yields

$$\theta^\star = \frac{1}{2} \cdot \frac{\gamma - 2 \cdot \beta}{\gamma - 2 \cdot \beta - \sqrt{k^{max}(\gamma - 2\beta)^2}.} \tag{28}$$

This implies the following: Because of assumption 3.1 (p 9) we can compute for every given input-share the condition, that introducing software patents leads to a higher optimal growth. Figure 2 depicts some examples. As one can see, the general result is, that the higher the share of

Figure 2: Relative Change of α and β and Input-Share



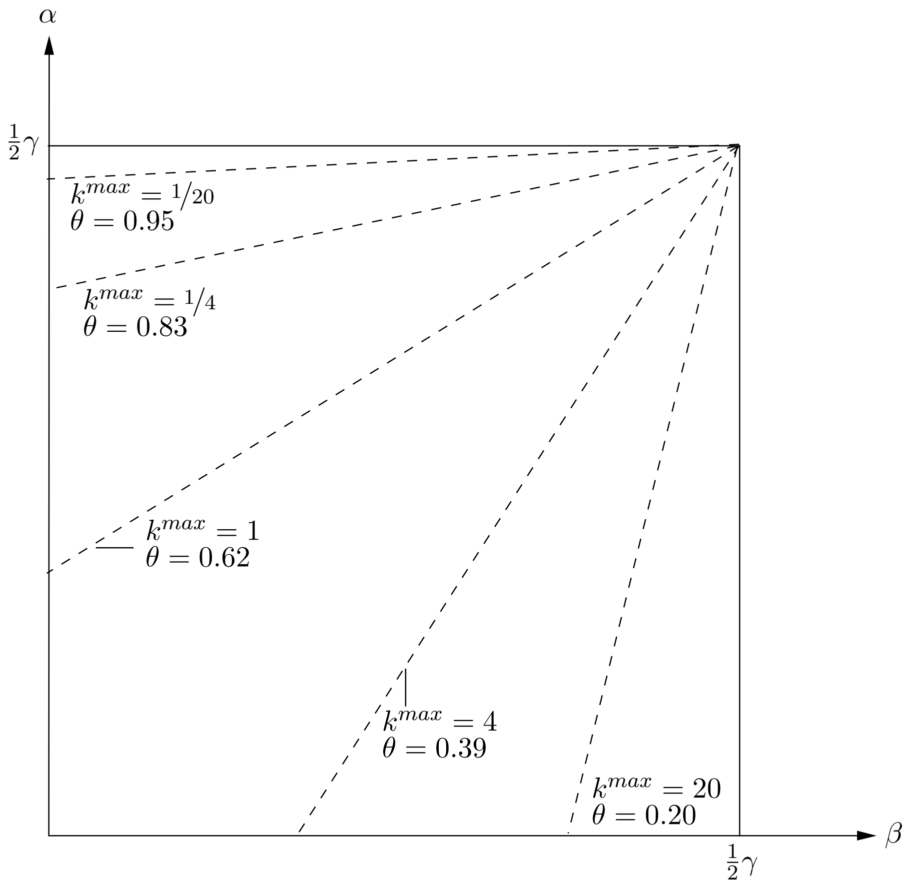
OSS, the stronger the condition, i.e. the higher θ the smaller the k^{max}. A smaller k^{max} means that either positive impact on the CSS sector has to be higher, or the negative impact on OSS has to be smaller or both. For example in case of $k = 1$, i.e. $d\alpha = -d\beta$ the condition for $d\dot{Y}^{\star} > 0$ is $\theta \leq 0.5$.

However, in case of $d\gamma = 0$ it depends on $\theta^{\star}$, whether introducing software patents are more likely increasing or decreasing optimal growth.

- $d\gamma \neq 0$, in this case, $d\gamma$ either weakens or strengthens the condition. Hence, in case of $d\gamma > 0$ software patents are more likely to increase growth, as now the condition for $d\dot{Y}^{\star}(T) > 0$ is

$$d\beta(2\alpha - \gamma)^2 + d\gamma(2\alpha - \gamma)(2\beta - \gamma) > -d\alpha(2\beta - \gamma)^2, \qquad (29)$$

Figure 3: Case with $d\gamma = d\beta > 0$

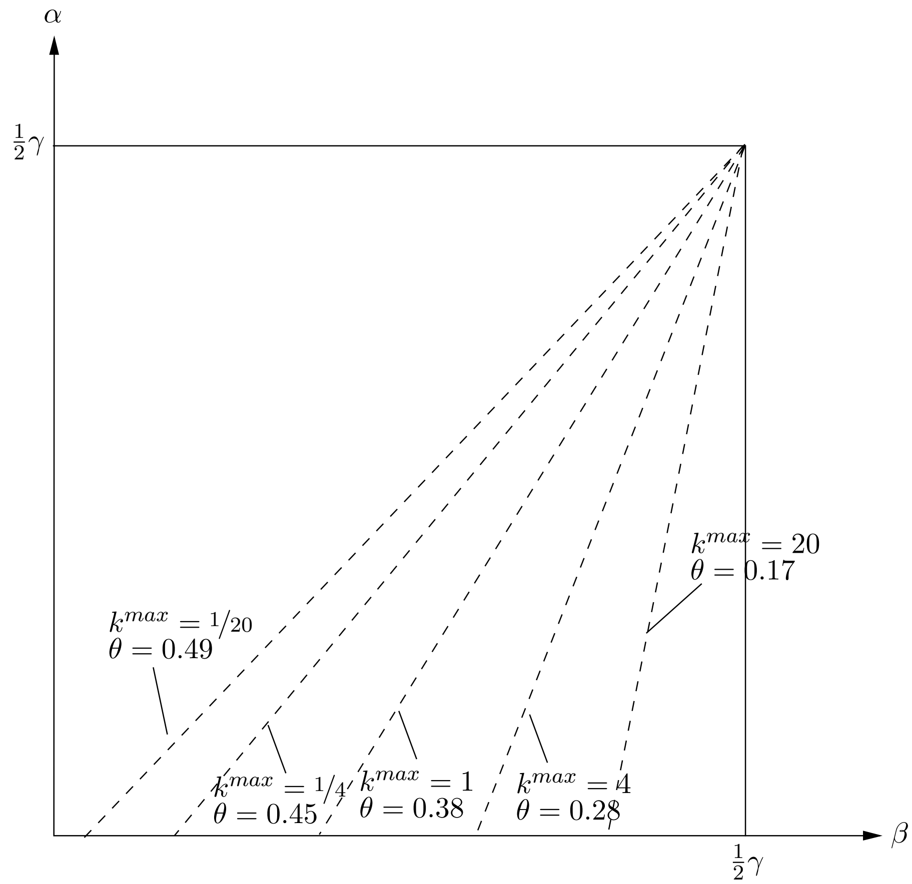


while in case of $d\gamma < 0$ this is

$$d\beta(2\alpha - \gamma)^2 > -\left[d\gamma(2\alpha - \gamma)(2\beta - \gamma) + d\alpha(2\beta - \gamma)^2\right]. \qquad (30)$$

As this seems to be quite intuitive, we do not want to go into details here. Anyhow, in order to provide a visual impression of the impact of $d\gamma \neq 0$, figure 3 and figure 4 depicts the boundaries for the same k-values as in figure 2. The figure 3 represents the situation for $d\gamma = d\beta > 0$, while the figure 4 represents the $d\gamma = -d\beta < 0$ case. Thus, if one compares the situation with no change of the interdependent parts of productivity growth (figure 2) with figure 3, one can see how $d\gamma = d\beta > 0$ weakens the condition, as i.e. in the case of $k = 1$ introducing software patents would increase growth only if $\theta \leq 0.62$—in the $d\gamma = 0$ case, it was $\theta \leq 0.5$.

Figure 4: Case with $d\gamma = -d\beta < 0$



> Additionally, if one compares figure 2 with figure 4, one can see how $d\gamma = -d\beta < 0$ strengthens the condition such that in case of $k = 1$ introducing software patents would increase growth only if $\theta \leq 0.38$.

To sum up: Although our general assumptions regarding the impact of patents were more or less 'patent friendly', it is not unlikely, that introducing software patents *decrease* optimal growth. Given that the economy's actual input-share θ is always equal the growth optimal $\theta^{\star}$, one can say, that introducing software patents more likely increases growth, the smaller the input share of OSS, i.e. the higher the share of CSS.

4 Summary

In this paper, we developed a simple model in order to examine the impact of IPR on the co-existence of OSS and CSS and the resultant innovative growth. Our main findings can be summarized as follows:

(a) It is possible to have a mixture of OSS and CSS that is growth optimal. In other words, we show that there is a co-existence and observe how IPL affects this co-existence using the spillover argument.

(b) We further find that it is not important for the benefits of intra-spillover activity to be equal. The sum of interdependent parts of productivity growth is what determines innovative growth. This result is similar to the function of adapters in networks and the spillovers can be interpreted as being network externalities. This means that a policy measure that increases one of the interdependent parts of productivity yields a superior situation even if this implies a decrease for the other part. The important thing is that the sum of interdependent parts increases overall.

(c) We find that changing from non-protection to copyright protection increases the optimal growth rate1 i.e. both sectors are better off than before.

(d) Economic literature (Bessen & Hunt 2004*a*, Hall & Ziedonis 2001, Bessen & Maskin 2000) points out that the use of patent protection for software is still fraught with much debate and the effects are not completely clear. In our model, we observe scenarios where $d\dot{Y}^{\star} > 0$ and where $d\dot{Y}^{\star} < 0$. Whether there is a positive or negative effect depends on the one hand on where the equilibrium of the industry was before and on the other hand the effect it has on productivity and spillover capacities.

In this context, public policy should perhaps focus on measures that increase either the basic niveau of productivity within the sectors or on the interdependent parts of productivity growth (or both) without affecting the autonomous part of productivity growth negatively.

The co-existence of OSS and CSS is still an area in the literature that needs further examination. Our paper is admittedly just a moderate step towards addressing this phenomenon. Thus, further theoretical as well as empirical research examining the co-existence and interaction of OSS and CSS in the context of IPR is required.

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