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An economic analysis of enterprise adoption of open source software

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Abstract

The emergence of open source and Linux has burdened IT managers with the challenge of whether, when, and in what applications to adopt open source software in their firms. We characterize the conditions under which enterprises adopt open source software. We show that adoption depends crucially on network effects, the fit of software with the range of applications used by each firm, and the IT capabilities of a firm. Our model predicts that most firms will adopt a heterogeneous IT architecture that consists ofopen source and proprietary software. The equilibrium adoption is often socially inefficient. This is the first paper in the open source literature to model the enterprise adoption of open source.

Keywords: Open source software, Linux, IT management, IT architecture, IT capabilities, technology adoption.

[+] The authors contributed equally and the names appear in alphabetical order. We thank Net Institute for supporting this research with a summer 2005 research grant.

1. Introduction

Linux and open-source software is an important emerging movement in the software industry. IDC predicts double-digit growth of Linux adoption.[1] The U.S. President's Information Technology Advisory Committee (2000) recommended direct subsidies for open source projects to advance high-end computing.

The academic literature has recently paid significant attention to the development of open source software (Lerner and Tirole 2004). Notably, this literature seems to ignore the *adoption* of open-source software, focusing instead on the supply-side of the software industry. Nevertheless, IT managers face tremendous challenges in making decisions on adoption of open source products (Golden 2005). Policy makers need guidelines to understand the social welfare implications from open source software adoption. Proprietary software firms and open source software distributors need to understand how they can optimize their marketing strategies based on the factors that shape the enterprise adoption of software products. The critical question is who will adopt open source software, and for what application?

This is the first paper to analyze enterprise adoption of open source software, and, in particular, to characterize the conditions under which firms adopt open-source software. Therefore we contribute to the open source literature by investigating an important but unexplored so far theme. The paper also contributes to the technology adoption literature.

Another contribution of the research is that we attempt to model real information technology (IT) management and IT adoption issues, looking into specific aspects of the IT infrastructure, an approach neglected by economics research and often by information systems economics research, as well. We capture important IT aspects, such as the heterogeneity of firms' applications and capabilities, and concerns of IT managers, such as the optimization of their IT architecture and IT investment, into economic modeling. The paper helps IT managers optimize their IT investment decisions taking into account

[1] eWeek reports "IDC sees double digit growth continuing for Linux," Dec. 8 2004 at http://www.eweek.com/article2/0,1759,1737068,00.asp.

the emergence of open source software and characterizes the IT architecture equilibrium of firms.

In our model firms are heterogeneous in terms of their *IT capabilities*. Also every firm uses a range of applications, from server-based enterprise applications, to client-based personal productivity applications. This range of applications defines the *IT architecture* of the firm. The choice of a firm is whether to use an open source or a proprietary software infrastructure for each application, so that it maximizes the value of its whole IT architecture. There are also network effects that depend on the installed base of each application and a misfit cost which captures the fact that a given software product is ideal for some applications but less "fit" for other applications.

We find that there are a number of adoption patterns that depend on the strength of the network effect and the misfit cost for the applications. Most often firms have a heterogeneous software infrastructure using both proprietary and open source software. The higher the IT capabilities of a firm the more it adopts open source software. Low IT capability firms may adopt proprietary infrastructure for all their applications, and firms with strong IT capabilities may adopt only open source for all their applications. These results are consistent with evidence from the IT press. For example, a survey of IT managers by Information Week shows that 60% of the firms have mixed IT architecture, 2% exclusively open source and 38% exclusively commercial.[2] The equilibrium adoption is not socially optimal. The market does not internalize the network externalities, as much as a social planner does. The equilibrium adoption of open source or proprietary software might be socially excessive.

The structure of the paper is the following. First, we discuss the existing open source literature. Section 3 presents a first simple model of enterprise adoption of open source, which does not consider the whole range of applications in the enterprise, but analyzes in-depth differences in terms of basic functionality, network effects and derivative value of proprietary and open source software. Section 4 presents the main model of the paper and its analysis. Section 5 presents some concluding remarks.

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[2] Information Week, Nov. 1st 2004, "Open Source software use joins the mix", (http://www.informationweek.com/story/showArticle.jhtml?articleID=51201599)

2. Overview of Open Source Software Literature

The economics literature on open source focuses mainly on the individual incentives to participate in open source projects, the incentives of firms to adopt open source initiatives, the business models of firms operating within the open source landscape, and the competitive implications of open source software (Lerner and Tirole 2004, Rossi 2004). Johnson (2002) models the contribution to an open-source project as a problem of private provision of a public good and analyzes the effect of increasing the number of developers. Lerner and Tirole (2001, 2002) discuss the incentives of individual programmers and software firms to participate in open source projects. They argue that programmers are motivated by "peer recognition" and delayed career benefits such as being hired by a software firm, or getting access to funding for future software ventures. Firms participate because they make money from complementary applications or services, get access to development talent that they may hire in the future, learn about the competition and open-source technologies, and promote open standards (possibly competing to other proprietary standards). Mustonen (2003) proposes a model in which the participation of programmers in open-source projects is endogenous and shows that a low implementation cost of an open-source application is crucial for its survival when it competes with a proprietary application. Bitzer and Schroder (2003) consider competition in technology, rather than prices or quantities, in a software duopoly market. Casadesus-Masanell and Ghemawat (2003) studies a dynamic setting of competition between Windows and Linux. Economides and Katsamakas (2005a) analyze the strategic differences between a proprietary and an open-source technology platform. Economides and Katsamakas (2005b) study the innovation incentives of application and platform developers. Mustonen (2005) analyzes when a proprietary software firm may support the development of substitute open source software. Comino and Manenti (2004) assume informed and uninformed users about the existence of open-source applications, and study the welfare implications of public policies supporting open-source software. Von Hippel and von Krogh (2003) argue that open source software development combines elements of the private and the collective innovation models. Hann et al (2004) examine empirically the benefits of individual participation in open source projects. DiBonna (1999), Raymond (2001) and Fink (2003) provide good overviews.

3. A Simple Model

Open source products differ from proprietary products in many perspectives. Anecdotal evidence suggests that the most influential factor that drives the customers' adoption decision is low cost and "openness" of open source software. Openness provides customers with the ability to access the source code, easily modify the base product and derive further applications (Fink, 2003; Rosenberg, 2000). However, the value of openness, which we call *derivative value,* is not necessarily the same to all firms. For example, firms with higher IT competence are capable of deriving higher value from the open source product (Dedrick and West, 2004).

In the current model, we focus on three key factors which can differ between proprietary and open source software. These are price, basic functionalities, and potential derivative values, which also differ across customers depending on their IT competence.

In particular, there are two products in the market: one open source product (O) and one proprietary product (P). The marginal production costs for both are zero. Customers can download the open source product for free and have access to the source code, or purchase the proprietary product at a price p without access to the source code.[3] Customers are heterogeneous in their IT competence, which is captured by θ ($\theta \in [0,1]$, with c.d.f. $F(\theta)$). There is a continuum mass 1 of customers. Customers benefit both from the functions of the software by itself and from positive consumption externalities within the same product network, assuming incompatibility. We assume an additive utility function, following many other studies (Economides and Himmelberg, 1995; Farrell and Saloner, 1986). A customer that adopts the product $i = P,O$ gets utility:

[3] Since the basic model focuses on the adoption side, we will treat this price as exogenous. Making this price endogenous, can be part of the model extensions.

$$u_P(\theta) = K_P(\theta) + h(n_P) - p, or$$
$$u_O(\theta) = K_O(\theta) + h(n_O)$$

where $h(n_i)$ is the benefit from product $i's$ network externality, and $K_i(\theta)$ is the stand-alone value of product i for customers of type θ. The stand-alone value of the software product comes from two sources: functions that are enabled by the software, called *basic functionalities*, and functions that can be developed from the software by modifying and extending the source code or using the application program interfaces (APIs) provided, called *derivative value*. The value of the basic functionalities are assumed to be homogenous among customers (s_i, $i = O$ or P).[4] On the other hand, the derivative value is an increasing function of the customer's technical competence--the higher IT capability the firms have, the higher derivative value they are able to gain from the software. Without loss of generality, we assume linear function as $a_i\theta$ ($a_i > 0$), where the increasing rate a_i is a feature of the software product depending on its support for further application development. Firms could incur costs for further development. We abstract this away, and assume $a_i\theta$ represents the final benefit of the derivative value. Hence,

$$K_i(\theta) = s_i + a_i\theta, i = O \text{ or } P$$

Depending on specific setting or software application, s_O or a_O can be greater, equal or smaller than s_P or a_P respectively. Indeed, open source software's "openness" offers easy access to the source code and a cheap (even free) access to a global pool of IT intelligence, hence may increase its power to facilitate further development (higher a_O). On the other hand, the vendor of the proprietary software has total control over the product design, provision of APIs, marketing and coordination of the developers' network (Economides and Katsamakas 2005a). It's possible that under certain scenarios, the proprietary software has higher a_P. We will characterize the equilibria under these different scenarios, and interpret the results in real-life practical examples.

[4] Further extensions involving the dimensions of customer heterogeneity will be discussed.

To simplify the formulas, we assume the benefit from network externality is linearly increasing with the number of adopters:

$$h(n_i) = en_i, i = O \text{ or } P.$$

In the analysis that follows, we solve a static game where all customers decide on which software to adopt simultaneously.[5] The analysis focuses on the conditions under which firms adopt open-source software, and the implications for the social welfare.

Simple Model Analysis and results

There are six cases depending on the relative value of the model parameters. In the following we summarize these cases.

Case 1 $s_O \leq s_P - p$ ***and*** $a_P \geq a_O$

The social optimal choice of technology is all customers adopt the proprietary software. Nevertheless, there are multiple equilibria in the customers' non-cooperative technology adoption game even when one product obviously dominates the other one.

- All customers adopt the proprietary software is always an equilibrium regardless of the magnitude of network externality. No customer has incentive to deviate given the superiority of the proprietary software and benefit from network externality.
- If the network effect is very strong compared with the superiority of the proprietary software ($s_P - p + a_P - s_O - a_O \leq e$) , there exists an equilibrium where all customers adopt the inferior open source product.
- If the network effect is moderate compared with the superiority of the proprietary software ($(a_P - a_O)/2 < e < s_P - p + a_P - s_O - a_O$), there exists an equilibrium where customers with IT competency $\theta \geq (e + s_P - p - s_O)/(2e - a_P + a_O)$ adopt the proprietary product while the less IT competence firms adopt the open source product.

[5] One could extend this setting into a dynamic setting where customers make decisions sequentially.

- If the network effect is not large compared with the superiority of the proprietary software ($e < (a_P - a_O)/2$), the only equilibrium has all the firms adopt the superior proprietary software product.

In summary, the social optimal outcome occurs when all firms adopt the superior proprietary software product. If the incremental network benefit from one more firm joining a network is not too large compared with the superiority of the proprietary product, the social optimal outcome is the only equilibrium.

Case 2 $0 < s_P - p < s_O \leq s_P$ ***and*** $a_P \geq a_O$

The socially optimal choice of technology is all customers adopt the proprietary software. On the other hand, the relatively high price makes the proprietary software less attractive to the less IT competent firms. At equilibrium, the social optimal outcome may occur if the network externality is in an appropriate range. In comparison with a relatively low price (case 1) ($s_P - p \geq s_O$ and $a_P \geq a_O$), there is lower probability that the socially optimal case will occur, since it is more likely that some or all customers adopt the low cost open source software because of the proprietary software's relatively high price.

- If the network externality is strong ($s_O - (s_P - p) \leq e$), there exists one equilibrium where all customers adopt the proprietary product.
- If network externality is strong enough ($s_P - p + a_P - (s_O + a_O) \leq e$), there exists one equilibrium where all customers adopt the open source product.
- For the rest of the cases ($e < \min[s_O - (s_P - p), s_P - p + a_P - (s_O + a_O)]$), there exist equilibria where some customers adopt the proprietary product ($\theta > (s_O - (s_P - p) - e)/(a_P - a_O - 2e)$) while others adopt the open source product.

Case 3 $s_P < s_O$ ***and*** $a_P \geq a_O$

The social optimal outcome is not obvious in this case, depending on the tradeoff between the benefit from network externalities and the benefit from basic functionality and derivative value. Each of the three cases may be social optimal (all customers adopt the proprietary product, all customers adopt the open source product or some adopt the proprietary while others adopt the open source product), depending on the value of the parameters. The equilibrium results are the same to the above case where $0 < s_P - p < s_O \leq s_P$ and $a_P \geq a_O$, since the adjusted quality $s_P - p$ is all that the customers care about. In this case, the social planner has to be careful while considering which choice is optimal. The critical concerns include the distribution of IT competence among all firms ($F(\theta)$), benefit from network effects ($h(n)$) and the technology superiority of one product over the other (s_P, s_O and a_P, a_O).

Case 4 $s_P \leq s_O$ ***and*** $a_P < a_O$

The social optimal outcome is to have all customers adopt the open source product. The fulfilled expectation equilibria are the following:

- All customers adopt the open source software is always an equilibrium regardless of the magnitude of network externality. No customer has incentive to deviate given the superiority of the open source software and benefit from network externality.
- If the network effect is very strong compared with the superiority of the open source software ($s_O + a_O - (s_P - p + a_P) \leq e$) , there exists an equilibrium where all customers adopt the inferior proprietary product
- If the network effect is moderate compared with the superiority of the open source software ($(a_O - a_P)/2 < e < s_O + a_O - (s_P - p + a_P)$), there exists an equilibrium where customers with IT competency $\theta \geq (s_O - (s_P - p) + e)/(2e + a_P - a_O)$ adopt the open source product while the less IT competent firms adopt the proprietary product.
- If the network effect is not large compared with the superiority of the open source software ($e \leq (a_O - a_P)/2$), the only equilibrium has all the firms adopt the superior open source software product.

This case is symmetric to case 1. The dominance of Apache in the web server market could be an example of this case.

Case 5 $s_P - p \leq s_O < s_P$ ***and*** $a_P < a_O$

The social optimal outcome is not obvious in this case, depending on the tradeoff between benefit from network externalities and benefit from better product fit. Each of the three cases may be social optimal (all customers adopt the proprietary product, all customers adopt the open source product or some adopt the proprietary while others adopt the open source product), depending on the value of the parameters. The equilibrium results are the same to the above case where $s_P \le s_O$ and $a_P < a_O$, since the adjusted quality $s_P - p$ is all that the customers care about. Realize that although it's likely to see all customers adopt the open source software, especially when network effects are not very strong, this may not be a social optimal outcome. Less IT competent firms may benefit more from a lower-priced proprietary product, given its high quality in basic functionalities.

Case 6 $s_O < s_P - p$ ***and*** $a_P < a_O$

The social optimal outcome is not obvious in this case, depending on the tradeoff between benefit from network effect and that from better product fit, and the value of the parameters. Each of the three cases may be social optimal (all customers adopt the proprietary product, all customers adopt the open source product or some adopt the proprietary while others adopt the open source product). The less IT competent firms may benefit more from a lower-priced proprietary product, given its high quality in basic functionalities.

4. Main Model

In this model, the proprietary software vendor can influence the market equilibrium by setting price *p* for its product. In addition, firms' adoption decision involves a range of applications.

Firms are heterogeneous with respect to their IT capabilities, which are indexed by θ. θ is assumed to be uniformly distributed in [0, 1]. A larger θ means better IT capabilities and the firm gets more value out of its IT applications. There is a continuum of firms of mass 1.

Each firm uses a range of applications, from core enterprise applications (server-side), to desktop personal productivity applications. There is a continuum of applications uniformly distributed in [0, 1]. The proprietary software (W) and the open source software (L) are differentiated based on which application each software fits the most. Without loss of generality, we assume the proprietary software is located at 0, and the open source software is located at 1. If a firm adopts W or L for an application that does not locate at 0 or 1, then it incurs a product misfit cost of c per unit "distance". The whole range of applications used by each firm defines its *IT architecture*. Each firm adopts L or W for each one of its applications, in order to maximize the total value that the firm gets from the whole range of applications it uses[6]. The model allows firms to use L for some applications and W for other applications, if that is the IT architecture they find optimal.

The better the IT capabilities of a firm the more value it can get out of adopting open source. A firm with strong IT capabilities can take advantage of the openness of the code to customize their infrastructure, and are able to manage and support effectively the deployment of open source architecture. Firms with weak IT capabilities may find it difficult to get significant value out of open source, or they risk a failure, because there is no vendor to provide them with ready solutions and comprehensive support. We assume that the firms' IT capabilities do not affect the value the firm gets from adopting W.

The cost structure of adopting L versus W is different. W requires a substantial fixed cost C_L to customize it and make sure it works for your company, but the cost of using it in more applications is almost zero (e.g. Google scaled its Linux infrastructure on thousands of servers without having to pay a licensing fee for each server). The cost of using W is mostly variable and depends on how many applications you use, and the licensing fee p set by firm W**.**

A firm that uses both L and W in its infrastructure incurs an extra fixed cost C_H because it needs to manage a heterogeneous infrastructure, incur higher staffing costs, and deal with potential incompatibilities. Deploying and managing a heterogeneous infrastructure is clearly more costly than managing a homogeneous infrastructure (only L or only W).

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[6] The assumption here is that IT adoption decisions are made in a centralized optimal way in each firm. It would be interesting to relax this assumption and examine the implications of other IT governance structures (see Weil and Ross 2004).

The value that firm θ gets from its IT architecture by adopting W for $t(\theta)$ fraction of its applications that are close to W is $U(\theta) = u_{\theta,L} + u_{\theta,W} - C_H$, where $u_{\theta,L}$, $u_{\theta,W}$ is the value derived from L and W respectively:

$$u_{\theta,L} = \int_{t_\theta}^{1} (\theta - c(1-t))dt - C_L + h_L(\theta) \text{ and}$$

$$u_{\theta,W} = \int_{0}^{t_\theta} (V_W - ct - p)dt + h_W(\theta).$$

$V_W \in [0,1]$ is the value for a W application, c is the reduction of the application value (fit cost) depending on the distance t of the application from the location of L or W respectively.

Firm θ benefits from network effects $h_L(\theta)$, $h_W(\theta)$ that depend on how many other firms adopt the same infrastructure (L or W) for the same range of applications. We assume linear network effect functions:

$$h_L(\theta) = e\left[(1-\theta)(1-t_\theta) + \int_0^\theta (1-t(x))dx\right] \text{ and } h_W(\theta) = e\left[\theta t_\theta + \int_\theta^1 t(x)dx\right]$$

In the specification above, *e* is the intensity of the network effects. It's well-established in the literatures on network goods that when the network effect is strong, consumers could be locked in one of the competing technologies. Nevertheless, this is not the only focus of the current model. To incorporate more effects from other variables, we restrict the magnitude of the network effect and assume that $e < 1/4$.

Figure 1, depicts important aspects of the setup of our model.

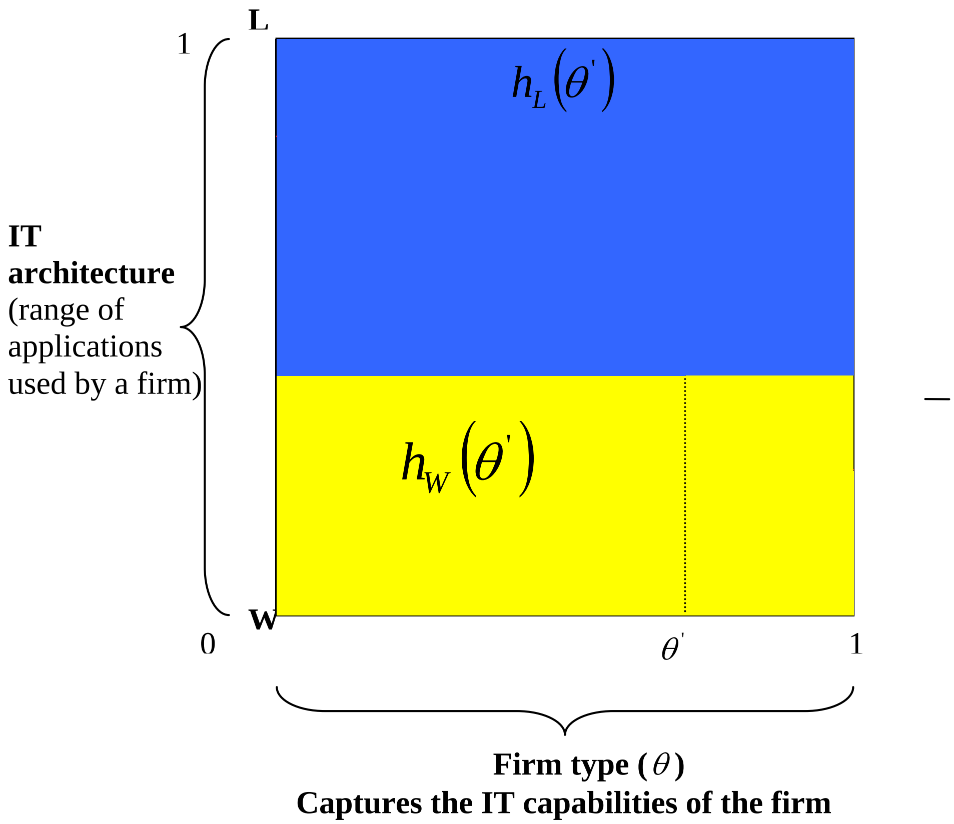

Figure 1 Firm IT capabilities and IT architecture

4.1 Open source adoption patterns

A firm's IT adoption problem:

$$\max_{t_\theta} U(\theta) \quad s.t. 0 \le t_\theta \le 1$$

The IT architecture value maximization condition gives

$$t_\theta = \frac{(2e-1)\theta + c - e + V_W - p}{2c} \equiv t(\theta)$$

Therefore, we have $t(0) = \dfrac{c - e + V_W - p}{2c}$, and $t(1) = \dfrac{e - 1 + c + V_W - p}{2c}$.

There are six possible adoption patterns listed in table 1.

Pattern	Constraint	Condition	Adoption pattern	W's Profit function
1	$t(0) \le 0$ and $t(1) < 0$	$p \ge V_W - e + c$	All firms adopt only L.	$\pi = 0$
2	$0 < t(0) \le 1$ and $t(1) \le 0$	$p < V_W - e + c$ $V_W - e - c \le p$ $V_W + c - (1-e) < p$	Firms with $\theta \le \frac{c-e+V_W-p}{1-2e}$ adopt both W and L; firms with $\theta > \frac{c-e+V_W-p}{1-2e}$ adopt only L.	$\pi = p\int_0^{\frac{c-e+V_W-p}{1-2e}} t(\theta)d\theta$
3	$0 < t(0) \le 1$ and $t(1) > 0$	$p < V_W - e + c$ $V_W - e - c \le p$ $p < V_W + c - (1-e)$	All firms adopt both L and W	$\pi = p\int_0^1 t(\theta)d\theta$
4	$t(0) > 1$ and $t(1) < 0$	$p < V_W - e - c$ $V_W + c - (1-e) < p$	Clients with $\theta \le \frac{c+e-V_W+p}{(2e-1)}$ only adopt W; clients with $\frac{c+e-V_W+p}{(2e-1)} \le \theta \le \frac{c-e+V_W-p}{1-2e}$ adopt both W and L; clients with $\theta > \frac{c-e+V_W-p}{1-2e}$ adopt only L.	$\pi = p\left[\frac{c+e-V_W+p}{(2e-1)} + \int_{\frac{c+e-V_W+p}{(2e-1)}}^{\frac{c-e+V_W-p}{1-2e}} t(\theta)d\theta\right]$
5	$t(0) > 1$ and $0 \le t(1) < 1$	$p < V_W - e - c$ $V_W - c - (1-e) < p$ $p < V_W + c - (1-e)$	Firms with $\theta \le \frac{c+e-V_W+p}{(2e-1)}$ adopt only W; firms with $\theta > \frac{c+e-V_W+p}{(2e-1)}$ adopt both W and L.	$\pi = p\left[\frac{c+e-V_W+p}{(2e-1)} + \int_{\frac{c+e-V_W+p}{(2e-1)}}^{1} t(\theta)d\theta\right]$
6	$t(0) > 1$ and $t(1) > 1$	$p < V_W - c - (1-e)$	All firms adopt only W.	$\pi = p$

Table 1 Adoption patterns conditions and W's profits

The maximal price that W can set and have positive sales is $V_W - e + c$. This is decreasing on the network effect parameter *e*. This happens because an increase of the W price *p* benefits its competitor L the more the stronger the network effect parameter *e*. In addition, the maximal price that W can charge and still have the whole market is $V_W - c - (1-e)$, which is an increasing function of *e*. The reason is the increasing value of the product with increasing adoption base.

The following figure shows all the possible patterns of adoption.

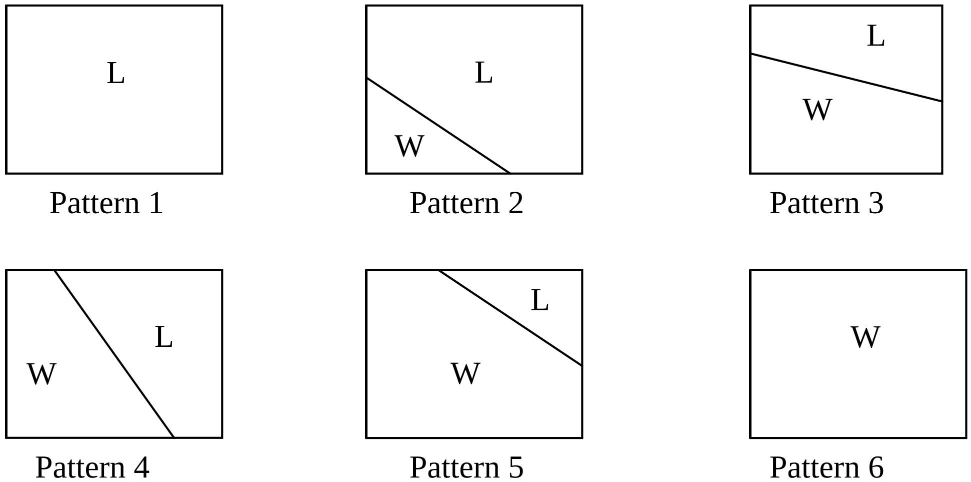

Figure 2 Patterns of software adoption

4.2 Profitability of proprietary firm

We solve for the optimal pricing under each case listed in table 1, assuming $V_W = .5$, and then compare the maximum profits for all cases to determine the profit-maximizing price and profit.

The technical analysis appears in the Appendix. The final optimal price and profit at equilibrium are the following:

(E1) If $e + c > 1/2$ and $2e + c > 1$, then $p^* = c/2$ and $\pi = c/8$, $t_\theta = \frac{(2e-1)\theta + c/2 - e + 0.5}{2c}$ (case 3).

(E2) If $e + c > 1/2$ and $2e + c < 1$, then $p^* = (c - e + 0.5)/3$ and $\pi = \frac{1}{c(1-2e)}\left(\frac{c-e+0.5}{3}\right)^3$, $t_\theta = \frac{(2e-1)\theta + 2(c - e + 0.5)/3}{2c}$ (case 2).

(E3) If $e + c < 1/2$ and $2c + e \geq 1/2$, then $p^* = (c - e + 0.5)/3$ and $\pi = \frac{1}{c(1-2e)}\left(\frac{c-e+0.5}{3}\right)^3$ $t_\theta = \frac{(2e-1)\theta + 2(c - e + 0.5)/3}{2c}$ (case 2).

The monopolist's profit is an increasing function of both the cost of product misfit parameter *c* and the network externality parameter *e*, which is consistent with the results from literatures on network externalities and product differentiation. The equilibrium market condition depends on the magnitude of these two parameters. When the sum of *c* and *e* is relatively small, the vendor has less market power. The low "type" firms adopt both products and the high "type" firms adopt only L. Increase in *c* and *e* makes it more and more costly for the high type firms to adopt L for applications that W fits better (located closer to W), hence gives the vendor more market power. Accordingly, the line that divides the market between L and W is getting flatter with increasing *c* and *e*, as shown in figure 3. When both *c* and *e* are relatively large, all firms adopt both W and L for some applications under equilibrium. (We assume C_L, C_H close to zero.)

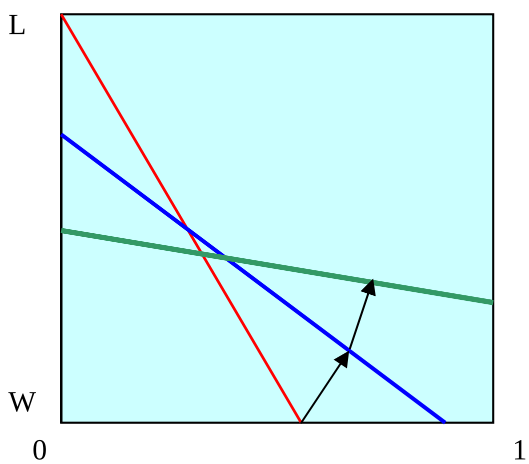

Figure 3 Equilibrium adoption with increasing *c* and *e*

4.3 Social welfare

We determine the socially optimal adoption pattern and compare it with the market equilibrium. A social planner maximizes the total surplus, that is:

$$\max_{t(\theta)} \int_0^1 \left[\int_{t_\theta}^{1} (\theta - c(1-t))dt - C_L + h_L(\theta) + \int_0^{t_\theta} (V_W - ct)dt + h_W(\theta) - C_H \right] d\theta$$

Solving for the optimization problem, we have the social optimal adoption pattern is:

$$t^S(\theta) = -\frac{1}{2c}(1-4e)\theta + \frac{1}{2c}\left(\frac{1}{2} + c - 2e\right)$$

The social planner has to consider a tradeoff between social surplus from product fit and that from network externality, which is related to the installed base of W or L in any one application. The social surplus from network effect is maximized when the market division line is flat, so for each application all firms use W or all firms use L. On the other hand, the social surplus from product fit is maximized when the division line is decreasing, so that high type firms use L for more applications than low type firms. To maximize the total social surplus, the social planner needs to balance these two effects.

The result shows that the social optimal market share between W and L involves a division line that is flatter than the one in the market equilibrium. When c is relatively large compared to e, in particular $c>2e$ or $c>4e-0.5$ when $0.25-0.5e<c<1-2e$, the difference in slope between the social optimal outcome and the market equilibrium is relatively small, which suggests a smaller surplus loss from network externality. The social optimal outcome leads to a market division line that is strictly above the one from market equilibrium. In other words, the social planner would like all firms to adopt more applications from W. This implies that when the product fit cost is high, the proprietary firm W charges too much for the software. Then, the social welfare loss is mostly from loss in product fit.

As c decreases, the difference in slope between the two division lines increases, and the two division lines move toward each other. Hence, more and more social surplus loss comes from loss in network externality, and less and less comes from loss in product fit. The two division lines will finally cross.

Figure 4 below shows areas for inefficient adoption for each possible equilibrium condition (E1)-(E3). As one can observe, the equilibrium division line is always steeper than the socially optimal market division line.

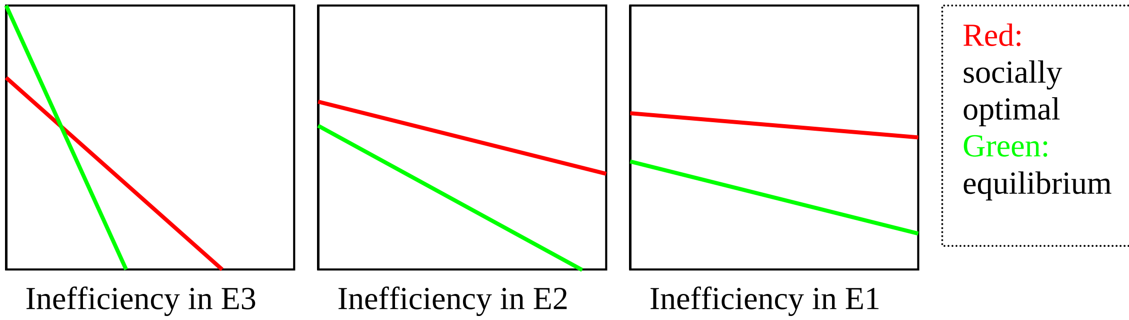

Figure 4 Areas of inefficient adoption are between the red and green line

In (E1), all firms inefficiently adopt L for more applications than it is socially optimal. The inefficiency is larger, the stronger the IT capabilities of the firm. In (E2), the pattern is similar, only now the high IT capability firms inefficiently adopt only open source.

In (E3) the socially optimal division is much steeper than in (E1), (E2). We observe both excessive adoption of proprietary architecture by the low type firms and excessive adoption of open source architecture by the medium to high type firms.

4.4 Benchmark case: W monopoly

When only W is available in the market, then W is a monopolist and the value that firms get from adopting W is $U(\theta) = \int_0^{t_\theta} (V_W - ct - p)dt + et_\theta$. Each firm maximizes the value of its IT architecture as follows:

$$\max_{t_\theta} U(\theta) \quad s.t. 0 \le t_\theta \le 1$$

Solving for the optimization problem, we have $t_\theta = \frac{V_W + e - p}{c}$.

The constraints are $\frac{V_W + e - p}{c} \le 1 \Leftrightarrow V_W + e - c \le p$ and

$\frac{V_W + e - p}{c} \geq 0 \Leftrightarrow p \leq V_W + e$. Thus if $p < V_W + e - c$ then all firms adopt W for all applications; if $V_W + e - c \leq p \leq V_W + e$ then all firms adopt W for $\frac{V_W + e - p}{c}$ of their applications; if $p > V_W + e$ then no one adopt W for any application.

The monopolist's profit function is

$$\pi = pt_\theta = p\frac{V_W + e - p}{c}$$

The monopolist's problem is:

$$\max_p \pi \quad s.t. \quad V_W + e - c \leq p \leq V_W + e$$

First order condition gives $p = \frac{V_W + e}{2}$. Then $t_\theta = \frac{V_W + e}{2c}$ and $\pi = \frac{1}{4c}(V_W + e)^2 > 0$.

If $\frac{V_W + e}{2} \geq V_W + e - c \Leftrightarrow c \geq (V_W + e)/2$, then $p^* = (V_W + e)/2$ and $\pi = (V_W + e)^2 / 4c, t_\theta = (V_W + e)/2.$

If $\frac{V_W + e}{2} < V_W + e - c \Leftrightarrow c < (V_W + e)/2$, then $p^* = V_W + e - c, \pi = V_W + e - c$ and $t_\theta = 1.$

The monopolistic profit is an increasing function of the intensity of network externality, and a decreasing function of the product “fit” cost *c*. When the fit cost *c* is high, the firms’ valuation for applications decreases rapidly with the distance of the application from the location of W. Hence, it is too costly for the monopolist to lower the price so that firms adopt W for all applications. Therefore, the profit maximization price is set such that all firms only adopt W for the applications that are relatively “close” to the location of W (Figure 4). This creates a loss of social welfare similar to the classical deadweight loss. Here the welfare loss is not from pricing out of the market of some firms, but because *all firms* are unable to use applications that do not have a good “fit” with the platform of the monopolist.

On the other hand, when the misfit cost *c* is low, W sets a price so that all firms adopt W for all their applications. A stronger *e* benefits the monopolist, since the firms’ valuation for the product increases with the adoption base.

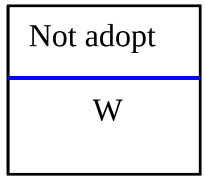

Figure 5 Adoption of W (monopoly)

As expected the W's profit under the monopoly case is higher than W's profit under competition from open source software.

5. Concluding remarks

Chief Information Officers and IT managers are actively considering the adoption of open source software within their IT architecture. In this paper, we developed analytical models to define the important dimensions of this decision and understand when and where firms adopt open source software.

We find that there are a number of adoption patterns that depend on the strength of the network effect and the misfit cost for the applications. Most often firms have a heterogeneous software infrastructure using both proprietary and open source software. The higher the IT capabilities of a firm the more it adopts open source software. Low IT capability firms may adopt proprietary infrastructure for all their applications, and firms with strong IT capabilities may adopt only open source for all their applications. These results are consistent with evidence from the IT press. The equilibrium adoption is not socially optimal. The market does not internalize the network externalities, as much as a social planner does. The equilibrium adoption of open source or proprietary software might be socially excessive.

Future research can collect data by surveying enterprise IT managers and empirically test hypotheses derived from the theoretical models developed here. Other research may also extend the model into other directions, such the dynamics of adoption, the strategic behavior of the open source community, and the impact of different IT governance structures on adoption decisions.

Appendix

Analysis of equilibrium Price and Profit (4.2)

There are six cases. First we solve each case and then we compare the maximum profits to determine the equilibrium price and profits.

Case 1

When price is too high, all firms adopt L or stay out of the market. No one adopt W. The monopolistic vendor's profit is equal to zero.

Case 2

$$\max_p \; p \int_0^{\frac{c-e+V_W-p}{1-2e}} t(\theta)\,d\theta$$
$$s.t.$$
$$0 < t(\theta=0) = \frac{c-e+V_W-p}{2c} \le 1$$
$$t(\theta=1) = \frac{e-1+c+V_W-p}{2c} \le 0$$

We solve the optimization problem by firstly using first order condition, and then check the inequality constraints. F.O.C. gives

$$(c-e+V_W-p)(c-e+V_W-3p) = 0 \Rightarrow$$
$$p = c-e+V_W \text{ or } 3p = c-e+V_W$$

It's easy to see that $p = c-e+V_W$ is the minimum, and $3p = c-e+V_W$ is the maximum. The constraints can be simplified as

$$\frac{c-e+V_W-p}{2c} > 0 \Leftrightarrow p < c-e+V_W$$
$$\frac{c-e+V_W-p}{2c} \le 1 \Leftrightarrow -c-e+V_W \le p$$
$$\frac{e-1+c+V_W-p}{2c} \le 0 \Leftrightarrow e-1+c+V_W \le p$$

If $e+c \ge 1/2$, then the constraints are reduced to $e-1+c+V_W \le p < c-e+V_W$; If $e+c < 1/2$, then the constraints are reduced to $-c-e+V_W \le p < c-e+V_W$. Now check with $p = (c-e+V_W)/3$:

$$\frac{(c-e+V_W)}{3} < c-e+V_W \Leftrightarrow c-e+V_W > 0$$
$$\frac{(c-e+V_W)}{3} \geq e-1+c+V_W \Leftrightarrow 2e+c \leq 1$$
$$\frac{(c-e+V_W)}{3} \geq V_W - c - e \Leftrightarrow 2c+e \geq 1/2$$

Therefore, if $e+c \geq 1/2$ and $2e+c \leq 1$, then $p^* = (c-e+V_W)/3$ and $\pi = \frac{1}{c(1-2e)}\left(\frac{c-e+0.5}{3}\right)^3$;

if $e+c \geq 1/2$ and $2e+c > 1$, then $p^* = e-0.5+c$ and $\pi = (e-0.5+c)(1-2e)\frac{1}{4c}$;

if $e+c < 1/2$ and $2c+e \geq 1/2$, then $p^* = (c-e+V_W)/3$ and $\pi = \frac{1}{c(1-2e)}\left(\frac{c-e+0.5}{3}\right)^3$;

if $e+c < 1/2$ and $2c+e < 1/2$, then $p^* = -c-e+0.5$ and $\pi = (0.5-c-e)c\frac{1}{(1-2e)}$.

Case 3

$$\max_p p\int_0^1 t(\theta)d\theta$$
$$s.t. 0 < t(\theta=0) = \frac{c-e+V_W-p}{2c} \leq 1$$
$$t(\theta=1) = \frac{e-1+c+V_W-p}{2c} > 0$$

We solve the optimization problem by using first order condition, and then check the inequality constraints. F.O.C. gives

$$\pi'_p = \frac{1}{4c}(2c+2V_W-4p-1) = 0 \Rightarrow$$
$$p = \frac{2c+2V_W-1}{4}$$

Since $e < \frac{1}{2}$, the constraints are simplified as

$$V_W - c - e \leq p < e-1+c+V_W$$

If $-c-e > e-1+c \Leftrightarrow \frac{1}{2} > e+c$, then this case is impossible. If $e+c > 1/2$, then since $V_W - c - e = 0.5-c-e < 0$, the constraint becomes

$$0 \leq p < e+c-0.5$$

Now check if the constraints are satisfied:

$$\frac{2c+2V_W-1}{4} \geq 0 \Leftrightarrow c \geq 0$$
$$\frac{2c+2V_W-1}{4} < e+c-0.5 \Leftrightarrow 1 < 2e+c$$

Hence if $1 < 2e+c$, then $p^* = c/2$ and $\pi = c/8$; otherwise $p^* = e+c-0.5$ and $\pi = \frac{(e+c-0.5)(1-2e)}{4c}$.

Case 4

$$\max_p p\left[\frac{c+e-V_W+p}{(2e-1)} + \int_{\frac{c+e-V_W+p}{(2e-1)}}^{\frac{c-e+V_W-p}{1-2e}} t(\theta)d\theta\right]$$
$$s.t.$$
$$t(\theta=0) = \frac{c-e+V_W-p}{2c} > 1$$
$$t(\theta=1) = \frac{e-1+c+V_W-p}{2c} < 0$$

It's easy to verify that the constraints are only valid when $e+c < 1/2$, and the constraints can be reduced to $0 \leq p < V_W - c - e$. First order derivative of the profit function is:

$$\pi_p^{'} = \frac{-e+V_W-p}{1-2e} - \frac{p}{1-2e}\left(\frac{c-V_W+e+p}{c}\right)$$

When $p = V_W - c - e$, the first order derivative is positive (= $\frac{c}{(1-2e)}$). Given the properties of the quadratic function, we have $p^* = V_W - c - e$ and $\pi = \frac{c(V_W-c-e)}{1-2e}$.

Case 5

$$\max_p p\left[\frac{c+e-V_W+p}{(2e-1)} + \int_{\frac{c+e-V_W+p}{(2e-1)}}^{1} t(\theta)d\theta\right]$$
$$s.t.$$
$$t(\theta=0) = \frac{c-e+V_W-p}{2c} > 1 \Leftrightarrow p < V_W - e - c$$
$$0 \leq t(\theta=1) = \frac{e-1+c+V_W-p}{2c} < 1 \Leftrightarrow 0 \leq e-1+c+V_W-p < 2c$$
$$\Leftrightarrow p \leq e-1+c+V_W \text{ and } e-1+V_W-c < p$$

The constraints are reduced to $e-1+V_W-c < p < V_W-e-c$ if $e+c > 1/2$. Since $V_W - e - c < 0$, this case is never optimal.

The constraints are reduced to $e-1+V_W-c < p < e-1+c+V_W = \quad e-0.5+c$ if $e+c < 1/2$. Since $e-0.5+c < 0$, this case is never optimal either.

Case 6

$$\begin{aligned}
&\max_p p \\
s.t.\, t(\theta = 0) &= \frac{c-e+V_W-p}{2c} > 1 \\
t(\theta = 1) &= \frac{e-1+c+V_W-p}{2c} > 1
\end{aligned}$$

The constraints can be simplified as:

$$\begin{aligned}
\frac{c-e+V_W-p}{2c} > 1 &\Leftrightarrow -e+V_W-c > p \\
\frac{e-1+c+V_W-p}{2c} > 1 &\Leftrightarrow e-1+V_W-c > p
\end{aligned}$$

Since $e < 1/2$, we have the optimal pricing and profit under the current case is

$$\begin{aligned}
p^* &= e-1+V_W-c \\
\pi &= e-1+V_W-c
\end{aligned}$$

When $V_W = 0.5$, the optimal pricing $p^* = e-0.5-c < 0$ and $\pi = e-0.5-c < 0$. Therefore this case cannot be optimal.

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