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DO TECHNOLOGY DIFFUSION THEORIES EXPLAIN THE OSS BUSINESS MODEL ADOPTION PATTERNS?

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ABSTRACT: This paper addresses the question of the software companies' timing of adoption of the open source software (OSS) business models comprising the ***supply*** of OSS products and/or services. The game-theoretic technology adoption models do not explain well the observed diffusion patterns of the OSS business model among the sample of 716 European software firms. Instead, it seems that the network effects influentially shape the diffusion path of the OSS supply strategies. Our study further contributes to the technology diffusion literature as our econometric model aims at separating, unlike the previous empirical studies on technology diffusion, the role that the replacement effect has in the diffusion patterns of new technologies. Our data detect a clear replacement effect hindering the incumbents' investments in new technology. The expected price declines of the computer programs – and thus the expected declining license revenues from the proprietary software – accelerate less the incumbent firms' timing of adoption of the OSS supply model than that of the entrants.

KEY WORDS: timing of technology adoption, diffusion, open source software, business models

JEL Classification: C41, D21, D23, L2, L86, O14.

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TIIVISTELMÄ: Tutkimuksen tarkoituksena on valottaa kysymystä avoimen lähdekoodin ohjelmistojen (OSS) tarjontaan perustuvien liiketoimintamallien käyttöönoton ajoituksesta ohjelmistoyrityksissä. Peliteoreettiset teknologioiden käyttöönottoa koskevat mallit eivät onnistu selittämään OSS -liiketoimintamallien leviämistä otoksen 716 eurooppalaisen ohjelmistoyrityksen joukossa. Sen sijaan verkostovaikutuksilla näyttäisi olevan huomattava vaikutus OSS -tarjontastrategioiden leviämiseen. Tutkimus tarjoaa myös kontribuution teknologioiden diffuusiota käsittelevään kirjallisuuteen: ekonometrinen malli erottaa, toisin kuin aiemmat empiiriset teknologioiden leviämistä koskevat tutkimukset, ns. syrjäytysvaikutuksen ("replacement effect"). Selvä vanhojen yritysten investointeja uusiin teknologioihin hidastava syrjäytysvaikutus on havaittavissa aineistomme valossa. Odottelu lasku ohjelmistojen hinnoissa – ja täten kaupallisista ohjelmistoista saaduissa lisenssituloissa – nopeuttaa markkinoilla toimivien yritysten OSS -liiketoimintamallien käyttöönottoa vähemmän kuin tapahtuu uusien, markkinoille tulevien yritysten kyseessä ollessa.

AVAINSANAT: Teknologioiden käyttöönoton ajoitus, diffuusio, avoimen lähdekoodin ohjelmat, liiketoimintamallit

JEL koodit: C41, D21, D23, L2, L86, O14.

1. Introduction

This paper addresses the question of the software companies' timing of adoption of the open source software (OSS) business models comprising the ***supply*** of OSS products and/or services. The dynamics of open source communities and particularly the motivation of software developers to participate the OSS development projects have been widely discussed in the economic literature (see, e.g., Lerner and Tirole, 2002). The increasing role of software companies in the OSS provision has intrigued industry observers but the diffusion dynamics and the drivers of the emerged private-collective business models involving both private investment incentives and the supply of public goods are still poorly understood. This study aims at shedding light on the questions: What determines the time path of the OSS business model adoption among software companies? Do economic theories on technology diffusion help in explaining the firms' adoption of the OSS business model?

The economic literature provides various complementary, and sometimes contradictory, theories on new technology adoption. The oldest and simplest, and not really economic theory based, explanation for the gradual, typically S-shaped diffusion of technologies over time, are the epidemic effects: innovations are assumed to spread like diseases when potential users are in contact with the technology users whom they learn about the new technology and immediately adopt it (see, e.g., Griliches, 1957). The rank effect theory proposes that the underlying reason for firms' different adoption times is heterogeneity in firms' ability to derive benefits from new technologies. The game-theoretic models emphasize that the firms' rivals adoption of a new technology has a negative influence for the benefits the firm can derive from it: both the number of adopters (the stock effect) and the firm's order in adoption (the order effect) matter (see Karshenas and Stoneman, 1993, for the first empirical study considering the order and stock effects, as well as the epidemic and rank effects). The network effect theory suggests the opposite: the greater number of users increases the firm's benefits from innovation (see, e.g, Saloner and Shepard, 1995). Generally, the empirical studies on technology diffusion provide strongest support for the presence of the epidemic and rank effects (Canepa and Stoneman, 2004).

This study further proposes that the *replacement effect* discussed primarily in the context of the firms' incentives to invest in R&D but neglected by the technology adoption studies may have a notable influence for the diffusion dynamics of innovations. The basic idea is that the incumbent company obtains a profit flow from the use of existing technology (here, the license revenues from proprietary software provision), and its investments in new technology (i.e. OSS supply) cannibalize these revenue streams. The market entrant, instead, has no profit flows to cannibalize. Thus, if both entrant and incumbent would gain the same benefits from innovation, the entrant's net benefit would be higher and it would adopt the technology earlier than the incumbent.

The study reported in this paper incorporates these theoretical explanations for the gradual technology diffusion to the single econometric model and explores how they manage to explain variation in the software firms' timing of adoption of the OSS business model. It uses a unique survey data collected collaboratively and simultaneously from the software industries of four European countries (Finland, Germany, Italy and Portugal[1]) to investigate differences in the timing of adoption of the OSS business strategies. Our data comprise information from 716 European software companies of which 306 (or about 43%) had implemented the OSS based business model by the time of the survey, the end of the year 2004.

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[1] The data were also collected from Spain but cannot be used for this study as information concerning firms' OSS adoption times is not available from Spain.

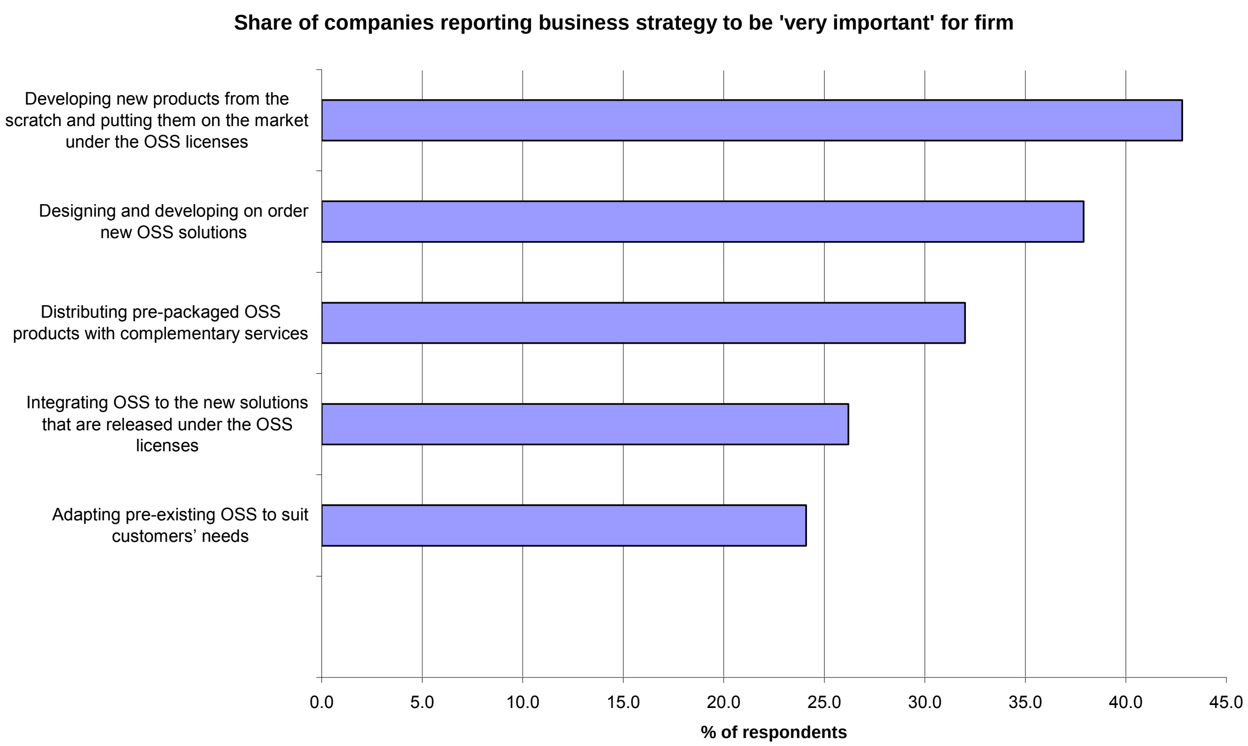
The data do not provide any support for the game-theoretic models of technology diffusion. The empirical findings are, instead, consistent with the presence of network effects. Our data indicate that the declining commercial software prices have accelerated the software firms' adoption of the OSS business model but, due to the replacement effect, the lowering prices have influenced less to the incumbent companies than the entrants. The further empirical finding that the older software firms - that have generally based their competencies on the proprietary software production and licensing - tend to adopt the OSS business model later is likely to reflect the competence destroying nature of the OSS business model.

The paper is organized as follows. Section 2 provides a theoretical framework for the adoption of the OSS business model. Section 3 introduces the data and discusses the explanatory variables of the estimated model. Section 4 presents the empirical findings. Section 5 concludes.

2. Timing of adoption of OSS business model

The OSS business model means here that a software firm not only uses the OSS but also distributes the OSS solutions, products and/or services. This strategy can either complement or replace the traditional commercial software licensing strategy. Our data indicate that often the firms combine the commercial licensing and the OSS supply: less than one third of the sample firms employing the OSS business model provide no proprietary software products. The OSS business model requires similar programming skills from the developers than does the production of commercially licensed software so the skills of the programmers of the incumbent companies do not become obsolete. The major difference is in the primary location of the development work from a firm's perspective – in-house vs. external development - and how the intellectual property rights are used for. The development and maintenance of the open source software happens largely outside of the company and the OSS licenses guarantee that no individual or firm can prevent others seeing, using or modifying the source code of the software. The General Public License (GPL) and other similar restrictive so-called copyleft license types further force the users and developers to maintain all modified versions of software in the public domain for everyone to use and develop, whereas the source code of the proprietary licensed software is closed, invisible for the users, and the property right owner is the only one allowed to modify and further develop the source code.

Figure 1. The importance of OSS strategies



There are various possibilities for the software companies to combine the traditional private investment and collective action based innovation models. A firm may provide *complementary services* to OSS, a*dapt pre-existing OSS to suit customers' needs*, *integrate OSS to the new solutions* that are released under the OSS licenses, design and develop *on order new OSS solutions,* and *develop new products from the scratch* and put them on the market under the OSS licenses. The respondents of our survey evaluated the importance of each strategy for the firm by choosing one of the three options: "not important", "nice to have" and "very important".

Interestingly, the shares of the responding firms reporting the five OSS business model categories to be 'very important' reveal that developing new OSS products from the scratch and on order are relatively more important than those strategies based on the use of the pre-existing OSS code (Figure 1). This finding is contrary to the view that from the firms' perspective the OSS community would primarily be a sort of public software development laboratory of which products software companies internalize and use for their own business purposes - the firms are also the origins of completely new open source software solutions. The complementary service strategy often emphasized in the literature seems also to be less valuable to the sample firms than the creation of their own OSS-licensed software solutions.

We assume, according to Karshenas and Stoneman (1993) and similar to Colombo and Mosconi (1995), that the gross benefits from the adoption of innovation are a function of the firm-specific factors and the number of technology adopters:

$$g_i(t) = g(C_i(\tau), K_i(\tau), K_i(t)) \qquad \tau \geq t. \qquad (1).$$

Here, $C_i(\tau)$ denotes those firm-specific factors, i.e. so called **rank effects**, that may affect the profitability and costs of innovation adoption, and $K_i(\tau)$ and $K_i(t)$ represent the number of the adopters of a technology. The net present value of an increase in a firm's gross profits from the OSS business model adoption can be written as follows:

$$G_i(t)=\int_t^{\infty} g(C_i(\tau),K_i(\tau),K_i(t))\exp\{-r(\tau-t)\}d\tau \quad (2),$$

where r is the discount rate.

We follow the literature on new technology adoption and define a firm's adoption date of the OSS business model as a time t when increase in the firm's profits due to innovation adoption exceeds its adoption costs:

$$Z_i(t)=G_i(t)-P_i(t)\geq 0 \quad (3),$$

where $P_i(t)$ the costs of the OSS business model adoption for a firm i at time t. Further, for adoption to take place the arbitrage condition has to hold: waiting can't be more profitable for a firm than adoption:

$$y_i(t)=d(Z_i(t)*\exp\{-rt\})/dt\leq 0 \quad (4).$$

Consequently, the optimal adoption date t_i^* of the OSS business model for firm i can be defined as $y_i(t_i^*)\leq 0$. A firm's adoption date can then be defined from equation (4) and, using equations (2) and (3), as follows:

$$y_i(t)=dg(C_i,K_i(t))/dK_i(t)(dK_i(t)/dt)(1/r)-g(C_i,K_i(t))+rP(t)-dP(t)/dt \quad (5).$$

In order to obtain a tractable econometric model for the empirical part of our study, we assume that g follows a linear functional form and add the parameters $(\gamma,\beta,\chi,\rho_1,\rho_2)$ of which values we want to estimate to the model. Equation (5) then becomes:

$$y_i(t)=\gamma\vartheta(dK_i(t)/dt)(1/r)-(\beta C_i+\chi K_i(t))+\rho_1 rP(t)-\rho_2 dP(t)/dt \quad (6),$$

where $\vartheta=dg(C_i,K_i(t))/dK_i(t)$, which is further set constant for our empirical model[2].

[2] This is done primarily as some of the cross product terms $C_i(dK_i(t)/dt)(1/r)$ appeared to be highly (>0.9) correlated with C_i.

We use the hazard function to capture the rate that the non-adoption spell is completed after duration t, given that it has lasted until time t: $\lambda_i(t|\theta) = \Pr\{y_i(t|\theta) + \varepsilon \leq 0\}$. Here, ε is a random error term that is assumed to remain invariant over time, and $\theta = \gamma, \beta, \chi, \rho_1, \rho_2$. We will next discuss the expected signs of these parameter values in the light of the different diffusion theories.

The variables $K_i(t)$ and $dK_i(t)/dt$ reflect the impact of the network size of the OSS-business model adopters and the expected change in the network size. The game-theoretic models of **stock and order effects** suggest that $K_i(t)$ relates negatively and $dK_i(t)/dt$ positively to the probability of a firm's adoption of innovation. The stock effect implies that the gross benefits from innovation for a firm decline with the number of its rivals' using innovation as their falling production costs affect negatively output prices on the market. Thus, the stock effects suggest a negative sign for χ. The order effect refers to the first mover advantages making a firm's returns from innovation adoption the higher the earlier it takes place compared to its competitors, and implies that γ gets a positive and χ a negative sign in the estimated equation. As both the order and stock effects suggest that the sign of χ is negative, we can make clear conclusions on the existence of the stock effects only if the estimate of γ is not statistically significant and positive supporting the presence of the order effect.

The adoption of the OSS business model differs from a traditional cost-reducing innovation adoption in certain respects, and we need to contemplate whether and how this may affect the stock and order effects. The open source supply is likely to involve also the use of the OS source code, which may – as certain open source licenses (e.g. BSD) allow firms to use the source code also for their proprietary software - reduce the firm's production costs of the proprietary software. A greater number of rivals providing the OSS may further decline output (software) prices as the open source licensed software is typically available at zero cost for the users. It seems possible that the adoption of the OSS business model also involves first mover advantages. For instance, an early OSS adopter may establish reputation as an innovative software solutions provider and obtain the leading position in the new market areas relying on the OSS[3].

The alternative theory on **network effects** suggests that the higher current and expected number of users of a new technology increases the present value of a firm's gains from new technology adoption. In the case of the OSS business model adoption, the indirect network effects may arise, e.g., as more rivals providing the OSS implies a greater stock of freely available source code that can be commercially exploited. The network effects may especially benefit those firms that both develop software products and provide supporting services for them. The network effect theory particularly emphasizes the role of expectations[4]: the greater expected network size may dramatically boost the diffusion speed of technologies. Therefore, we assume that if the network effects dominate the OSS business model diffusion both χ and γ get positive signs in the estimated equation.

The OSS can typically be acquired at zero price – so, what is the cost of the adoption of the OSS business model ($P(t)$) for a firm? For incumbent firms, the major cost of the OSS business model adoption comprises the foregone license revenues from their own commercially licensed software.[5] The production of completely new software typically

[3] Some major software companies such as IBM have openly and perceptively advertised their implementation of the OSS business strategies.

[4] Weiss (1994) reports the first empirical study explicitly investigating the impact of expectations on technology adoption. His study does not, however, consider the effect of the expected network sizes but focuses on the users' expectations on technological improvements.

[5] The costs of implementation of the OSS business model may also depend on various firm-specific characteristics such as firm size and age that are controlled by the rank effect variables (see Section 3 for a detailed discussion on these variables).

involves sizable development costs and close to zero marginal costs. Therefore the firms relying on the traditional commercial licensing strategy often have substantial sunk investments on R&D to recover. We can assume that for the market entrants this cost is zero as there are no prior investments and revenue streams to be lost - thus incumbents and entrants face different adoption costs of the OSS business model. This is the replacement effect that is used in the economic theory of innovation to explain analogously the differences in the monopolistic incumbents' and market entrants' incentives to undertake R&D (see, e.g., Tirole, 1998).

The expected future adoption costs of the OSS business model (i.e. the license revenues a firm could earn in the future), instead, also affect the decisions of the entrants as they consider whether it would be profitable to develop proprietary software. Thus the expected adoption prices may affect both the decisions of the incumbents and entrants. In our empirical model, we therefore divide the coefficient of the expected price change variable into two parts and re-write equation (6) as follows:

$$y_i(t) = \gamma\vartheta(dK_i(t)/dt)(1/r) - (\beta C_i + \chi K_i(t)) + \rho_1^I rP(t) - (\rho_2^I + \rho_2^E)dP(t)/dt \qquad (7),$$

where the upper indicator I denotes incumbents and E entrants (i.e. firms that have adopted the OSS business model at the time of market entry). If the replacement effect affects the adoption decisions of the incumbents and entrants as we propose, we should observe $\rho_2^I < \rho_2^E$.

One of the first explanations for a gradual diffusion of innovations was that a new technology spreads over the population of potential users as information on its availability spreads. Non-users learn from the experience of users and consequently adopt the new technology. Our econometric model controls for these so called epidemic effects.

3. Data and descriptive findings

3.1. Explanatory variables

This section introduces the explanatory variables used for empirically investigating the software firms' timing of adoption of the OSS business model. Table 1 provides a brief description and descriptive statistics of the variables.

i) Stock, order and network effects: We measure $K_i(t)$ by the variable ADOPT_SHARE that is derived as a proportion of the sample software firms that have adopted the OSS-business model in a firm's home country at the time of its own adoption. The expected change in the number of variable is captured by the variable ADOPT_GROWTH which is calculated as the percentual change in the number of adopters between time t and t-1. The signs of the estimated coefficients of these variables, χ and γ, reflect the existence of the stock, order and/or network effects as follows: positive χ and γ provides strong evidence for the network effects, whereas negative χ and positive γ provide strong support for the presence of the stock and order effects.

ii) Replacement effect: The firm's license revenues from commercial software depend essentially on the prices of commercially licensed software which we use to capture the replacement effect. The annual commercial software prices are calculated as the average of the two US producer price index categories – applications software and computer games and pre-packaged software – deflated by the general price changes in the sample countries (see Table 1). This is of course not a perfect measure for software prices but the best available, and its use can be justified on the basis of the openness and competitiveness of the global market for software – software prices are set internationally[6]. Though the software-product mix of the sample companies may vary

[6] Eurostat suggests in its "Handbook on price and volume measures in national accounts" (2001) that it is acceptable, though not ideal, to use the US index for packaged software in international comparisons.

Table 1. Description of the explanatory variables

Description of variable	Variable name	Mean	Standard deviation
PRICE= Mean U.S. producer price index for applications software and computer games and pre-packaged software[1] deflated by general price changes[2] at time firm adopts OSS business model & INCUMB=1 if firm has entered the market at least year before adopting OSS business model and 0 otherwise & r = long-term annual interest rates at time firm adopts OSS business model.	r*INCUMB*PRICE	2.623	1.417
ΔPRICE=(PRICE(t)-PRICE(t-1))/PRICE(t-1)*100, INCUMB=1 if firm has entered the market at least year before adopting OSS business model and 0 otherwise.	INCUMB*ΔPRICE	-2.873	2.370
ΔPRICE=(PRICE(t)-PRICE(t-1))/PRICE(t-1)*100, ENTRANT=1 if firm is market entrant at time it adopts OSS business model and 0 otherwise.	ENTRANT*ΔPRICE	-0.889	2.314
Share of software firms that have adopted OSS-business model in a firm's home country at time of its own adoption.	ADOPT_SHARE	0.324	0.155
ADOPT_GROWTH=(ADOPT_SHARE(t)-ADOPT_SHARE(t-1))/ADOPT_SHARE(t-1)*100 & r= long-term annual interest rates at time firm adopts OSS business model.	ADOPT_GROWTH*(1/r)	4.696	4.774
Dummy variable that gets value 1 if firm distributes web servers, and 0 otherwise.	SERVER	0.374	0.484
Dummy variable that gets value 1 if firm does not provide any software products but only services, and 0 otherwise.	PURE_SERVICE	0.127	0.333
Dummy variable that gets value 1 if firm is owned by another company, and 0 otherwise.	OWNER_OTHER	0.107	0.395
Firm's age at its time of adoption of the OSS-business model (or in 2004, for censored observations).	AGE	9.335	8.124
Dummy variable that gets value 1 if firm has less than 10 employees, and 0 otherwise.	MICRO	0.584	0.493
Dummy variable that gets value 1 if firm has more than 250 employees, and 0 otherwise.	LARGE	0.023	0.149
Dummy variable that gets value 1 if share of employees having at least university degree is higher than on average among our sample firms, and 0 otherwise.	EDUCATION	0.438	0.497
Dummy variable that gets value 1, if firm's home country is Finland, and 0 otherwise.	FINLAND	0.229	0.420
Dummy variable that gets value 1, if firm's home country is Germany, and 0 otherwise.	GERMANY	0.460	0.499
Dummy variable that gets value 1, if firm's home country is Portugal, and 0 otherwise.	PORTUGAL	0.142	0.350
Years elapsed since the first introduction of the OSS business model (among our sampled companies) until the firm's adoption of it.	TIME	11.437	2.492

1) Source:U.S. Department of Labor, Bureau of labor statistics data.
2) This is done by calculating the consumer prices of each country relative to the US consumer price. Consumer price indices are derived from Economic Outlook No 81: Annual and Quarterly data.
3) The OECD calculates the long-term (in most cases for 10 years) interest rates based on the government bond yields. Dataset: OECD Financial indicators MEI.

substantially and we do not have firm-level information on the prices of the supplied computer programs, we believe that our price variable is a sufficiently good proxy capturing the general declining trend of software prices. The expected changes in prices are measured as the observed percent change in the software prices between time t and t-1.[7]

According to the theory, both the actual and expected commercially licensed software prices negatively relate to the adoption of the OSS business model. The price level impacts only on the incumbents' adoption decisions, and the effect of the expected prices should be stronger for entrants than incumbents. To test this, we estimate a model that includes the price level variable for incumbents only (INCUMBENT*ΔPRICE), and the separate expected price variables for the incumbents and entrants, ENTRANT*ΔPRICE and INCUMBENT*ΔPRICE, where ENTRANT (INCUMBENT) is a dummy variable that gets value 1 if a firm is a market entrant (incumbent).

iii) Rank effects: We control for various firm-specific characteristics that may affect the (net) profitability of the OSS business model adoption. The previous empirical studies indicate that *firm size* and *age* are fundamental factors affecting both the adoption and production of innovations (see, e.g., Geroski, 2000). This is likely to be the case also here as the OSS business model may necessitate substantial organizational changes (e.g., towards more service-oriented business) and some prior competences of the company may become useless.[8] The recently established companies are building up their business from the scratch and have thus less competence to loose. The OSS supply model may also be very attractive to young and small firms of which resources to develop completely new software programs are modest as it may enable their existence

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[7] We believe this is a more realistic approach than assuming firms have a perfect foresight and using the real future price changes as an explanatory variable.

[8] The empirical study of Harison and Koski (2006) investigating firm characteristics distinguishing the OSS-business model adopters from non-adopters finds some support for the firm age variable but not for the firm size.

without launching any new products. Our hypothesis is thus that firm size and age relates negatively to the firm's probability to adopt the OSS business mode.

Unfortunately, we know the firm size (measured by the number of firms' employees) only for the year 2004. Particularly for those companies that have been among the early adopters, the size of the company may have substantially changed after the introduction of the OSS business model. We aim at minimizing this measurement problem by using the dummy variables that capture the firm's size class – the idea is that there are less changes between the size classes over time than in the number of employees: the variable MICRO that gets value 1 if a firm employs less than 10 people and the variable LARGE that gets value 1 if a firm employs more than 250 people. The variable AGE measures the firm's age at time of its OSS-business model adoption (or, in the case of censored observations, at the time of the survey).

The corporate status, i.e. whether the firm is independent or part of a larger organization, may affect its timing of adoption of innovation but the relationship is ambiguous. On the one hand, independent firms may be less bureaucratic and able to faster make and implement a decision to adopt a new technology. On the other hand, units belonging to the large organizations may bear less risk and be better informed about new technology, and thus adopt the technology faster. The variable OWNER_OTHER captures a firm's corporate status. It gets value 1 if the firm is owned by another company, and 0 otherwise.

We distinguish firms that provide merely services from those that provide a mix of software products and services or only software products. The pure software service providers are likely to be the first candidates adopting the OSS business model as they do not have to fear for cannibalizing their license revenues such as those firms that have based their business model more or less on the proprietary licensed software products.

Our hypothesis is that the dummy variable Pure_service positively relates to the probability of the OSS business model adoption.

In most software markets segments, the OSS has gained only a relatively small foothold and the commercial license provision has remained as the primary mode of software distribution. The market for the web servers provides a clear exception: the global market share of the Apache server has at times peaked to about 70% and challenged the commercial web server providers. The OSS has thus become a dominant standard in the market for the web servers. Some previous studies (see, e.g., Koski, 1999) suggest that standardization facilitates technology diffusion. Software suppliers may be inclined to supply the standard technology due to the demand of the end-users who benefit from network effects arising from the use of the standard. In software markets, thus, we may assume that those companies that function on the market for web servers tend to have a higher probability of the OSS business model adoption than other companies. The variable SERVER that takes value 1 if a firm distributes web servers, and 0 otherwise, is used for capturing this effect.

In addition to the firm-specific (or rank) effects, the diffusion speed of innovation may be affected by the *country-specific factors* such as the demand for the OSS products by the end-users. We use the dummy variables that capture the firm's country of origin to control for possible country-specific differences in the adoption patterns of the OSS business model.

iv) Epidemic effects: The epidemic effect is strongly correlated with time (see, e.g. Karshenas and Stoneman, 2003), and we use the variable TIME to capture the time trend. This variable measures calendar time elapsed since the year when the first sample company adopted the OSS business model. The epidemic effect implies that the coefficient of this variable takes a positive sign, i.e. the adoption becomes more likely over time.

4. Econometric model and empirical findings

The entrepreneurial open source software has a stamp of the new business model of the 21st century.[9] It is true that the importance and adoption rates of the OSS business models have substantially increased during the past few years: about 71% of the sampled open source software suppliers began OSS provision in or after the year 2000 and the peak of the OSS business model adoption has been the year 2000. However, as Figure 2 shows, many software companies - almost 30% of our sample - provided the open source solutions already in the 1990s.[10] Figure 3 further illustrates that the OSS business model has spread relatively slowly in our sampled countries until the end of the 1990s, which was followed by a somewhat steeper growth in the adoption rates, particularly in Italy.

The oldest of our sampled software companies have been established in the 1960s, prior to the time that the first open source licensed software were distributed. We calculate the time it took for a firm to adopt the OSS business model, $y(t_i^*)$, from the year 1991 which essentially covers the first observations of adoption among our sampled companies[11]. This is also the year when Linus Thorvalds launched the first version of the Linux operating system in the Internet marking the birth of a global community developing open source software. For the firms that were established after 1991, the failure time is calculated as the number of years it took for a firm to adopt the OSS business model after its establishment. The firms that had not adopted the OSS business model by the time of the survey were treated as right-censored observations.

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[9] See, e.g., "Open Season on Open Source?", *Business Week* 3/13/2006, Issue 3975, p.78-79.

[10] During the early years of software development sharing the code was more common than the commercially licensed software packages. Commercialization of the markets for software was opposed by some software developers such as Richard Stallman and created a movement supporting the open source software. The first open source licenses, the General Public License (GPL) and the Berkeley Software Distribution (BSD) license were developed during 1980s (Laat, 2005).

[11] We have three observations of OSS-based business model adoption before 1991 which we treat as outliers and exclude from the analysis.

Figure 2. Density function for the firms' timing of adoption of OSS based business models

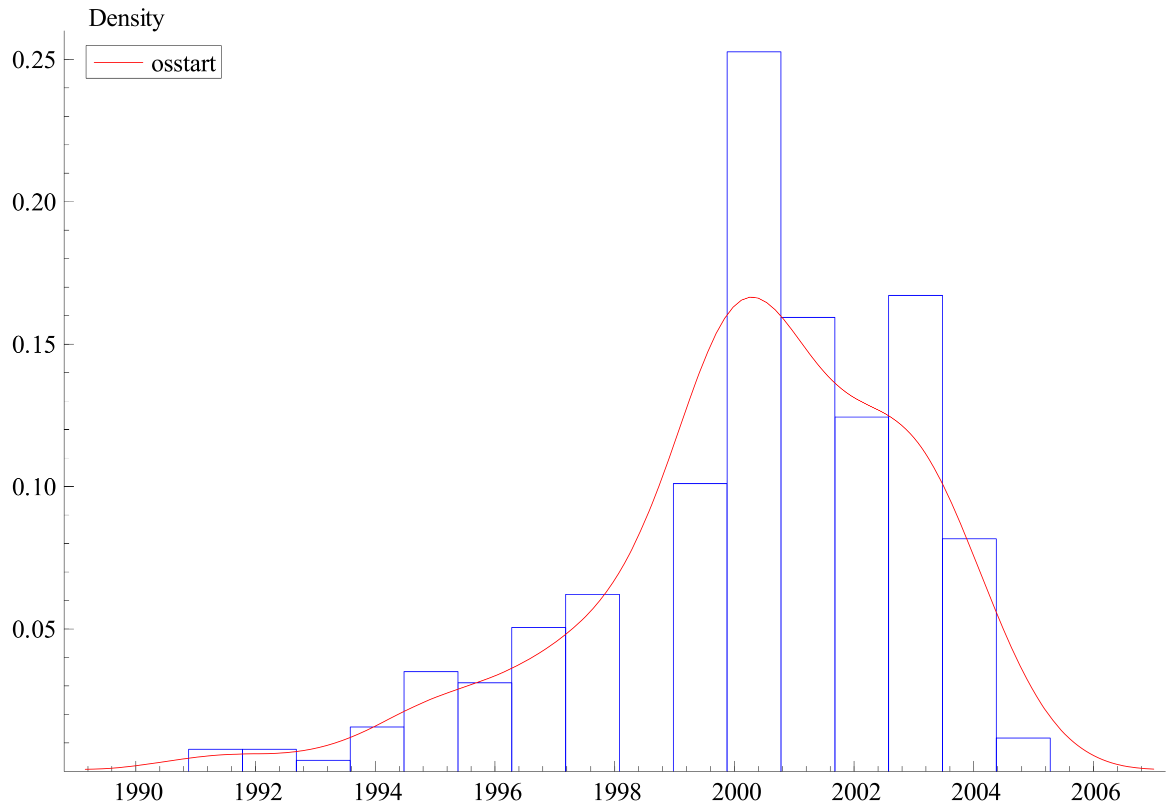
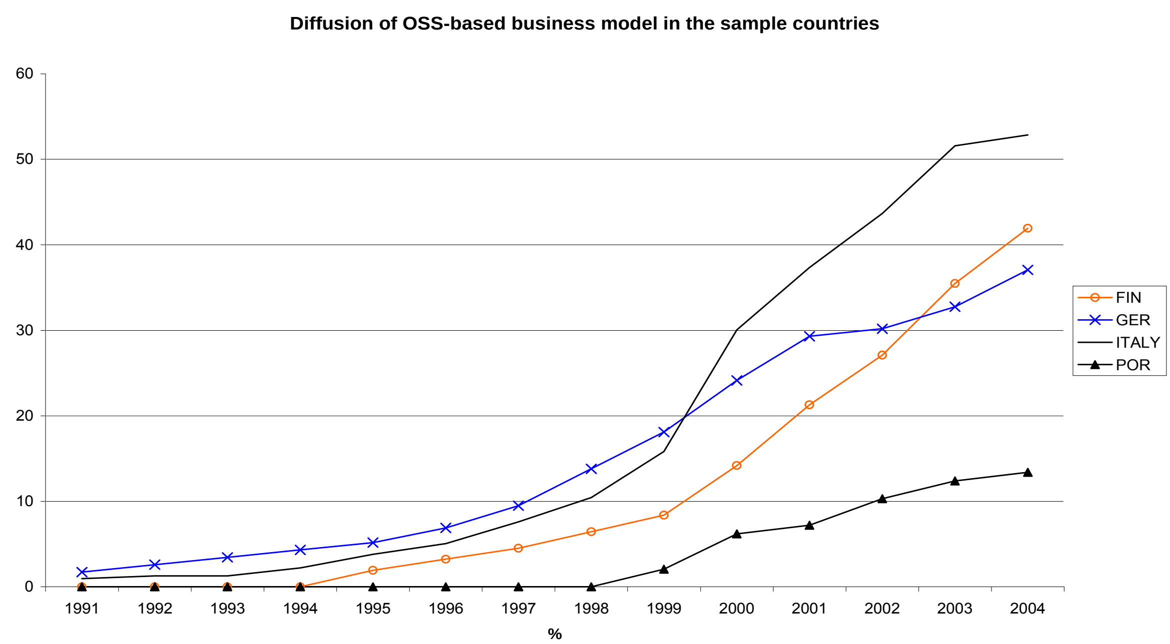


Figure 3. Diffusion of OSS business model use in the sample countries

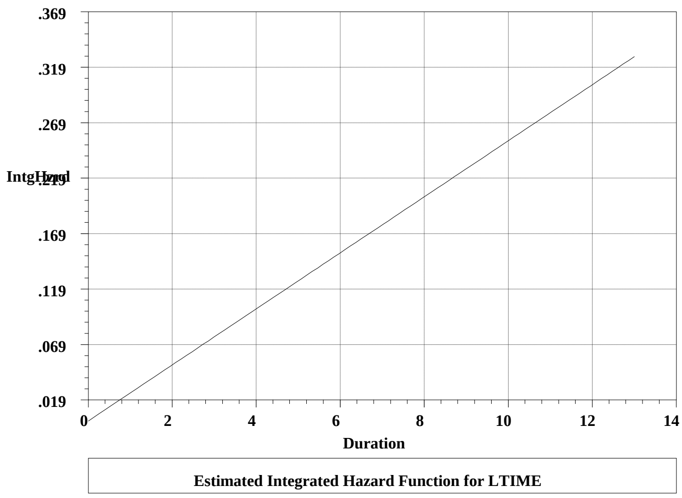


The likelihood function for the probability that a firm adopts the OSS business model after the given period of non-adoption can then be written in a general form as follows:

$$L(\theta) = \prod_{i \in A} f(t|\phi) \prod_{i \in C} S(t|\phi) \qquad (8)$$

, where A and C denote adopters and censored observations (i.e. non-adopters), respectively, and $f(t|\phi)$ is the density function for duration t and $S(t|\phi)$ is the survival function, i.e. the probability that the state of non-adoption is at least of length t.

Figure 4. The estimated integrated hazard function of the exponential model



We first estimated various survival models that made different assumptions concerning the underlying distribution of duration of non-adoption as the theory provides no guidance concerning the proper distributional assumption for our data.[12] We used the plots of the integrated hazard function to find the best among the estimated alternatives: the normal, log-logistic, Weibull and exponential model. The integrated hazard function should form a straight line departing from the origin when the model specification is correct. The exponential model was clearly giving the best fit in this respect (see Figure

[12] We used LIMDEP 8.0 in the estimations.

4), while the other estimated integrated hazard functions deviated from the expected straight line form. We therefore report here the estimation results of the exponential model of which likelihood takes the form:

$$L(\theta) = \prod_{i \in A} \lambda e^{-\lambda t} \prod_{i \in C} e^{-\lambda t} \qquad \text{(MODEL 1)}$$

, where $\lambda = e^{-\beta C_i - \gamma \vartheta (dK_i(t)/dt)(1/r) - \chi K_i(t) + \rho_1^I r P(t) - (\rho_2^I + \rho_2^E) dP(t)/dt}$.

We may note first that we have to be extremely careful in the interpretation of the estimation results of the individual variables that may change over time (such as firm size) as they generally represent the status of the firm at the time of the survey and not necessarily at the time of the adoption of the OSS business model. We introduce the unobserved heterogeneity term ν that we assume to capture the potential measurement errors or variation related to unobserved or uncontrolled factors. Then the density and survival functions take the form: $f(t|\theta,\nu)$ and $S(t|\theta,\nu)$. We assume that ν follows gamma distribution with mean 1 and variance $\theta = 1/k$. Then, the estimated model can be written as follows[13]:

$$L(\theta) = \prod_{i \in A} ([1 + \theta(\lambda t)]^{-1/\theta})^{\theta} \lambda e^{-\lambda t} \prod_{i \in C} [1 + \theta(\lambda t)]^{-1/\theta}. \qquad \text{(MODEL 2)}$$

When θ = 0, we have no heterogeneity, and the exponential model (MODEL 1) is derived. The estimated parameter value for θ and its statistical significance defines whether there exists unobserved heterogeneity that should be taken into account in the estimated model.

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[13] See Greene (2007) for the derivation of the Weibull survival model with gamma heterogeneity. The exponential survival model with gamma heterogeneity can be obtained straightforwardly by setting (his) scale parameter p to 0.

Table 2. The estimation results of the exponential model for the timing of adoption of the OSS business model (without price variables)

	MODEL 1	MODEL 1	MODEL 2
Constant	3.941 (13.202)	4.188 (11.580)	7.145 (6.396)
ADOPT_SHARE	**4.670** **(3.821)**	**5.406** **(3.847)**	**7.026** **(2.543)**
ADOPT_GROWTH*(1/r)	**0.048** **(4.468)**	**0.051** **(4.376)**	**0.087** **(3.015)**
SERVER	**0.389** **(3.300)**	**0.490** **(3.207)**	**0.789** **(2.739)**
PURE_SERVICE	0.234 (1.112)	0.054 (0.187)	0.164 (0.368)
OWNER_OTHER	0.017 (0.100)	0.073 (0.389)	0.062 (0.168)
AGE	**-0.467** **(-39.124)**	**-0.443** **(-26.968)**	**-0.485** **(-23.140)**
MICRO	0.033 (0.124)	-0.011 (-0.068)	0.350 (1.057)
LARGE	-0.010 (-0.300)	**-2.071** **(-2.503)**	-2.201 (-1.627)
EDUCATION		**0.464** **(3.410)**	**0.873** **(3.103)**
FINLAND	0.367 (1.878)	1.263 (2.723)	1.281 (1.521)
GERMANY	-0.316 (-1.752)	0.094 (0.318)	-0.342 (-0.506)
PORTUGAL	0.576 (1.191)	1.143 (1.832)	0.455 (-0.448)
TIME	**-0.477** **(-7.636)**	**-0.612** **(-8.036)**	**-0.869** **(-5.356)**
θ			**-1.432** **(-4.184)**
Number of observations	604	426	426
Log-likelihood	-725.557	-476.520	-432.806

We first estimated the model without the price variables as the price data is available only from the year 1997 onwards. Table 2 and 3 present the estimation results for Models 1 and 2 without and with the price variables, respectively. As there are plenty of missing observations concerning the variable EDUCATION – and its inclusion reduces

Table 3. The estimation results of the exponential model for the timing of adoption of the OSS business model (with price variables)

	MODEL 1	MODEL 1
Constant	**11.470 (10.256)**	**13.359 (8.616)**
INCUMBENT*PRICE	**-0.918 (-8.712)**	**-0.973 (-6.994)**
INCUMBENT*ΔPRICE	**-0.196 (-3.490)**	**-0.206 (-2.861)**
ENTRANT*ΔPRICE	**-0.366 (-6.453)**	**-0.279 (-3.309)**
ADOPT_SHARE	**9.315 (3.445)**	**11.815 (3.389)**
ADOPT_GROWTH*(1/r)	0.001 (0.046)	-0.005 (-0.187)
SERVER	0.205 (0.840)	0.208 (0.593)
PURE_SERVICE	-0.014 (-0.031)	-0.138 (-0.195)
OWNER_OTHER	-0.171 (-0.466)	-0.121 (-0.272)
AGE	**-0.196 (-8.519)**	**-0.200 (-6.421)**
MICRO	0.106 (0.466)	0.248 (0.656)
LARGE	1.834 (1.818)	24.928 (0.000)
EDUCATION		0.167 (0.548)
FINLAND	**0.962 (2.704)**	**1.885 (2.295)**
GERMANY	-0.338 (-0.858)	-0.169 (-0.241)
PORTUGAL	**1.914 (3.156)**	**2.680 (3.246)**
TIME	**-1.234 (-7.793)**	**-1.511 (-7.073)**
Number of observations	568	402
Log-likelihood	-332.235	-223.856

our sample substantially, from 604 observations to 426 observations - we estimated the models first without this variable. We may first note that, at least when the price variables are not included, the estimated parameter value for the unobserved heterogeneity term θ is statistically significant supporting the use of Model 2 (TABLE 2). The exponential-Gamma mixture function was not computable when the price terms were included so it remains unclear whether the inclusion of the prices variables eliminated this heterogeneity.

The prices of commercially licensed software do indeed matter: the higher software prices hinder the incumbent firms' adoption of the OSS-business model. Moreover, the expected prices are negatively and statistically significantly related both to the incumbents' and entrants' timing of adoption of the OSS business model. The estimated coefficient of variable ENTRANT*ΔPRICE is lower than the coefficient of the variable INCUMBENT*ΔPRICE indicating that the observed price decline has accelerated more the OSS-business model adoption of the entrants than that of incumbents. This finding supports the replacement effect theory: the incumbent companies react less to the declining profits from the traditional business model as supplying the OSS cannibalizes their license revenues from the proprietary software.

The estimation results of all model variations show that both χ and γ get positive values indicating that both the stock and the expected number of the rivals implementing the OSS business model increase the firm's probability of the OSS business model adoption. This finding is contrary to the presence of the stock and order effects, and instead, supports the dominance of the network effects. Interestingly, the estimated coefficient of the variable ADOPT_GROWTH is not statistically significant when the price variables are included to the econometric model (Table 3). This hints that the (expected) price decline of the commercially licensed software is intertwined with the expected changes in the future number of users. A credible explanation is that the expected price declines are the underlying cause of the expected increase in the future number of the OSS suppliers.

Those quite few previous empirical studies on the topic are generally consistent with our findings (see, e.g., Karshenas and Stoneman, 1993; Colombo and Mosconi, 1995). The empirical investigation of Mulligan and Llinares (2003) provides an exception. Their study on the diffusion of the detachable chairlifts in the United States finds support for the game-theoretic models, though it does not distinguish the stock and order effect. Also, Gourlay and Pendecost (2002) conclude that their empirical findings on the diffusion of the automated teller machines (ATMs) in the UK are consistent with the order effects as the expected number of users appears to explain statistically significantly banks' earlier ATM adoption. This finding might, however, as well reflect the presence of network effects[14] that our study finds to influentially shape the diffusion path of the OSS supply strategies.

The estimated coefficient of the variable TIME is statistically significant but it, contrary to the epidemic effect theory, gets negative value. This variable is supposed to capture the effect of the exogenous increase in information concerning the OSS business model over time. It seems possible that the variable ADOPT_SHARE comprises information spread from the adopters of the OSS business model to the non-adopters, and we cannot thus distinguish to what extent the network effect and the epidemic effect account for the statistical significance of the estimated coefficient of the variable ADOPT_SHARE.

When we control for the software prices, the rank effects – with the exception of the firm age - do not get statistically significant coefficients. The variables SERVER and EDUCATION are statistically significant only when the price variables are not included to the estimated equations (TABLE 2). The positive coefficient of the variable SERVER provides weak support to the finding of Harison and Koski (2006) using the Finnish data that the firms with relatively more highly educated employees can accrue greater

[14] The empirical study of Saloner and Shepard (1995) using the US data on the ATM adoption finds support for the presence of the network effects. They do not, however, use the (expected) number of adopters but the number of banks' branches as the explanatory variables to capture the network effects.

benefits from the OSS business model. The estimation results concerning the variable SERVER further hint that the standards may play role also in the business model adoption.

The estimated coefficient of the variable AGE is negative and highly statistically significant indicating that the older firms have been clearly less likely to adopt the OSS business model than recently established software companies. This hints that the OSS-business model has some characteristics of *radical organizational innovation* involving such new processes and competencies that some of the old incumbent firms' fundamental organizational capabilities – e.g., organizational routines, skills and strategies - become obsolete (Henderson, 1993).

Overall, our estimation results suggests that the older incumbents tend to stick (longer) to the business model relying on the supply of proprietary licensed software both because of their sunk investments in software development and their organizational investments built around the supply of commercially licensed software.

5. Conclusions

The game-theoretic technology adoption models do not explain well the observed diffusion patterns of the OSS business model among the sample European software firms. Instead, it seems that the network effects influentially shape the diffusion path of the OSS supply strategies. This network effect finding is consistent with the OSS literature emphasizing the role of the open source community and suggesting that the benefits that its members accrue increase with the size of the network of OSS developers.

This study further contributes to the technology diffusion literature as our econometric model aims at separating, unlike the previous empirical studies on technology diffusion, the role that the replacement effect has in the diffusion patterns of new technologies. Our data detect a clear replacement effect: the expected price declines of the computer programs, and thus the expected declining license revenues from the proprietary software, accelerate less the incumbent firms' timing of adoption of the OSS supply model than that of the entrants. This finding is rather interesting, shedding light on how a firm's strategic market position affects its timing of adoption of new technology and how the diffusion paths of different generations of technologies are intertwined. The expectations of the potential adopters and path-dependencies characterize the diffusion of new business models in the software sector.

Our data also indicate that the evolvement of the OSS business model has particularly challenged the old, incumbent companies of which competitive advantage has relied, by and large, on their accumulated experience on the market for proprietary software and the intellectual property they have sold in the form of software licenses. The competitive landscape is quite different when the market entrants can compete with the incumbents by using the OSS development community as their software development and maintenance unit, and the licensing revenues of various proprietary software products shrink with the declining software prices and the success of the open source program options that are available with the zero license costs.

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