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DOES OPEN INNOVATION FOSTER PRODUCTIVITY? EVIDENCE FROM OPEN SOURCE SOFTWARE (OSS) FIRMS***

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ABSTRACT: The primary findings of our study suggest that software firms that adopt the OSS-based business model are notably less productive than companies that merely offer proprietary software solutions. Our estimation results further show that the OSS business model adopters have not become notably less productive after beginning to supply OSS. Therefore, its seems that not the use of the OSS business model as such has reduced the OSS firms' labour productivity but the firms that employed the OSS business model during the sampled years were, on average, of lower labour productivity type. Though the OSS business model use has not substantially improved the performance of software firms, we find that the OSS business model adopters strategically using the source code made available by the OSS community as part of their new software products, have performed better in terms of labour productivity than other adopters of the OSS business model.

JEL Classification: D24, J24, L17, L86, O33

Key words: open source software, business strategies, open innovation, labor productivity

1. Introduction

The development of Open Source software (OSS) is embraced by larger numbers of software-developing firms as a part of their business strategy and in some cases as their main business model. Recent studies discussed the economic motivates and the strategies of software companies that favour participation in Open Source software (OSS) development and supply as strategic means over the traditional mode of marketing proprietary applications.

It is reasonable to expect that firms adopting an OSS-based business model do so to increase their profits. Hence, we can expect that the companies that benefit from the OSS business model adoption the most, would be the first in their sector to dismiss their software development practices in favour of adopting an OSS development methodology. McKelvey (2001) describes three modes of software supply that are used by firms for different strategic purposes, i.e. enhancing their profits, capturing larger market shares and creating de-facto market standards, which include provision of purely proprietary software, OSS and *hybrid* applications, which through versioning are partially proprietary and partially open/free. Harison and Cowan (2004) analyze how the degree of disclosure affects profits in various market scenarios and identify the pricing of hybrid software products as a proportion of their open features. West (2003) studies the economic trade-off between adoption and appropriability of operating systems and how it affects the implementation of open, proprietary and “mixed” strategies by software and hardware producers. He concludes that, on the one hand, when firms have developed multiple sources of revenues, such as provision of services or hardware (e.g. IBM and Sun), they enabled them to expand their user base and compensated for the loss of revenues from *direct* software sales, hence increasing profits through broader adoption of open systems and technical standards. On the other hand, firms that base their position mainly on software products (e.g. Microsoft) have succeeded in sustaining their position in the market and their profitability by maintaining their proprietary strategies, despite the introduction of free product alternatives. Henkel (2006) explains the choice of OSS in development of embedded technologies.[1] He argues that the use of particular OSS licenses (namely, variants of the GPL license) enables firms to reveal their source code and yet to protect their innovations and to appropriate from them. In this respect, firms that apply and benefit from the hybrid mode of software development can exercise *selective revealing*. They uncover the OSS-based segments that are embedded in their products while protecting the remaining sources of know-how that generate their profits.[2] Bonaccorsi et. al. (2006) found that the adoption of OSS-based strategies is hindered by switching costs and by the experience of the firm with proprietary software on the supply side and by network externalities of proprietary products on the demand side. Interestingly, the firm size had no significant effect on the decision to embrace OSS development. Fitzgerald's (2006) study of commercial and widely adopted OSS applications, named OSS 2.0 after the transition of OSS from community driven and voluntarily developed programs into commercial applications, argues that the evolution of OSS has blurred the distinction between proprietary products and "free" applications with the entry of large, profit seeking firms (e.g. IBM and Sun Microsystems) into OSS markets and attempts to preserve the communal environment of OSS development by those actors.

The empirical findings of Harison and Koski (2006) suggest a somewhat different perspective on the use of OSS strategies by software developing firms should be taken. OSS strategies can be explained as means for knowledge acquisition and development of *absorptive capacity* of firms - both are essential elements for innovation, firm survival and growth. In particular, the absorptive capacity reflects the ability of the firm to absorb, apply and draw commercial

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[1] The research studied firms that applied embedded versions of the Linux operating system in consumer electronics products and other devices, such as mobile phones, network routers and media players.

[2] Those findings are also affirmed by Lerner and Tirole (2005) who studied the use of OSS licenses by over 40,000 development projects listed in the SourceForge database. They found that software developed in corporate environments typically have restrictive licenses (namely GPL and its some variants).

benefits from external information or innovation produced outside its boundaries (Cohen and Levinthal, 1990). The greater the firm’s absorptive capacity the larger the benefits it can obtain from external innovation. Software firms adopting the OSS-based business model typically develop larger volumes of absorptive capacity (measured by the educational level of their employees) than companies that rely on different and more “traditional” business models.

Whether the expectations of those firms that have adopted the OSS business model for better economic benefits have materialized is a question to which the previous studies did not answer in quantitative and measurable ways. Further, if superior benefits from the use of OSS development exist, no measurements of their size and volume are provided in the economic literature.

Our study inquires whether the performance of software companies that have adopted a business model based on the supply of OSS significantly differs from the performance of firms that provide only proprietary software applications. It aims at addressing those issues by applying empirical approach linking a firm’s labour productivity to its strategic business model choices and by comparing, using the econometric analysis, the productivity levels among the firms.

The paper is built as follows: Section 2 reviews the properties of productivity in software production and the difficulties in measuring productivity in software developing firms. The third section presents the research method and the model used to estimate the productivity of firms. Section 4 presents and elaborates the results of the study. Finally, we conclude and provide policy implications and future venues along which the research can be expanded.

2. The Productivity of Software Developers: Drawing Lessons from Proprietary Software to OSS

Productivity is the major determinant of the performance and competitiveness of firms. It can be enhanced either via improvements in production technology or via organizational changes, such as the adoption of new business practices that improve the efficiencies of organizing and exploiting human and physical capital, technical know-how and the intellectual resources within firms.

The OSS-based business practices can be used in various ways to enhance the productivity of software developing firms: First, firms can reduce labour inputs by completely or partially substituting the produced source code of its products with existing code that has been developed by Open Source communities. Second, beyond developing the source code, various stages of the development process (including testing, documentation and technical support) require substantial labour and capital investments. Firms can reduce or completely replace the expenses needed to carry out those activities by forming Open Source communities and using inputs from their members (Lakhani and von Hippel, 2003; Jeppesen and Frederiksen, 2006). The OSS model reflects the self-organization of OSS communities and the ‘quasi-chaotic’ distribution of software development task among their members (see Raymond, 1999)., and may possibly enable more efficient allocation and utilization of activities and resources throughout the design, the development and the testing of software applications than the traditional mode of in-house development within firms. Further, concerns over intellectual property involved in development of proprietary software require governance and management structures that may create additional inefficiencies, require managerial labour and auditing costs and prevent more efficient allocation of resources to programming (Kogut and Metiu, 2001). It is not, however, self-evident that the OSS business model adoption would provide efficiency gains for the firms. Involvement in the open source supply may also create inefficiencies from the firm's point of view, for instance, if the employees spend their working hours developing modes of OSS that subsequently will not provide monetary benefits or efficiency gains, directly or via complementary service provision, for the firm.

Our paper aims at examining whether there is a notable difference in the labour productivity of firms that apply the OSS business model and companies that base their activities on the production of proprietary applications. Then, we reveal how different types of business practices that are based on OSS development affect the productivity of software firms.

3. Methodology

The data used in this study were collected by a web survey[3] during the period of November 2004 – February 2005. We contacted 591 Finnish companies supplying software products and/or services by e-mail messages asking them to respond to our web questionnaire.[4] The data comprises responses from 170 firms (approx. 30 % response rate) and covers approximately 8 % of all firms in the software industry in Finland. Firms using OSS/proprietary strategies were distributed as follows: 73 firms supplied OSS products and/or services and 97 offered merely proprietary software or services. Additional information concerning the year the companies adopted OSS-based business models was later gathered from the respondents and merged with the financial data of the companies, compiled from the Asiakastieto database. We restricted the data used in the empirical analysis to cover only

[3] The questionnaire used for our web survey was developed in collaboration with the Italian, Spanish, Portuguese and German partners – who undertake a similar survey, with the exception of few country-specific questions, in their countries – of the ELISS (European Libre Software Survey) project. Further information regarding the questionnaire is available from the authors.

[4] The first e-mail message was followed by several follow-up e-mails and by phone calls to the respondents.

those firms that were functioning in the computer and related activities sector (ISIC Rev. 3 class 72). Thereby, our database comprises of 492 observations from the responding companies from the years 1989-2004.

The performance of firms is measured by the real value added per employee (variable LP). The capital/labour ratio K/L (log real value of physical capital per employee) is a standard variable that is used in the Cobb-Douglas production function to estimate labour productivity.

We add to the estimated model other variables that can potentially explain the performance of the firm, following previous empirical studies that used them to explain the variation in firm-level productivity (For description of the variables, see Appendix A). We follow Maliranta and Rouvinen (2006), which estimate the impact of mobile ICT devices on the productivity of firms, and include the educational level of firm's employees (variable EDUC) in the model. The ownership structure (variable FOREIGN_OWN) is another important factor that can affect productivity by transfer of efficient work practices and technical and organizational know-how from foreign subsidiaries (Gomes-Casseres et. al., 2006; Cloodt et. al., 2006). Also firm's age (VARIABLE LYEARE) may influence its productivity: greater experience and established routines may enable older firms to function more efficiently than the younger ones. On the other hand, younger firms may be more flexible and more likely to employ organizational innovations enhancing labour productivity.

The location of the firm within a university city (variable UNICITY) and hence in proximity to universities generates opportunities for acquisition of new knowledge, e.g. by employing gradutes and students, through meetings between firm professionals and university researchers or by collaborating in joint research projects (Zucker et. al., 2002; Sorenson and Fleming, 2004). The possible relations between firms and universities may result in knowledge spillovers from the university to the firm and can enhance the productivity of its employees (see e.g. Siegel et. al., 2003). In addition, the application of an OSS-based strategy is aligned with the inherent culture of many universities and public research institutes and their preference to favour the development and use of OSS applications and thereby with the creation of professional links and knowledge transfer to those companies (see Schmidt and Schnitzer, 2003 and von Krogh et. al., 2003).

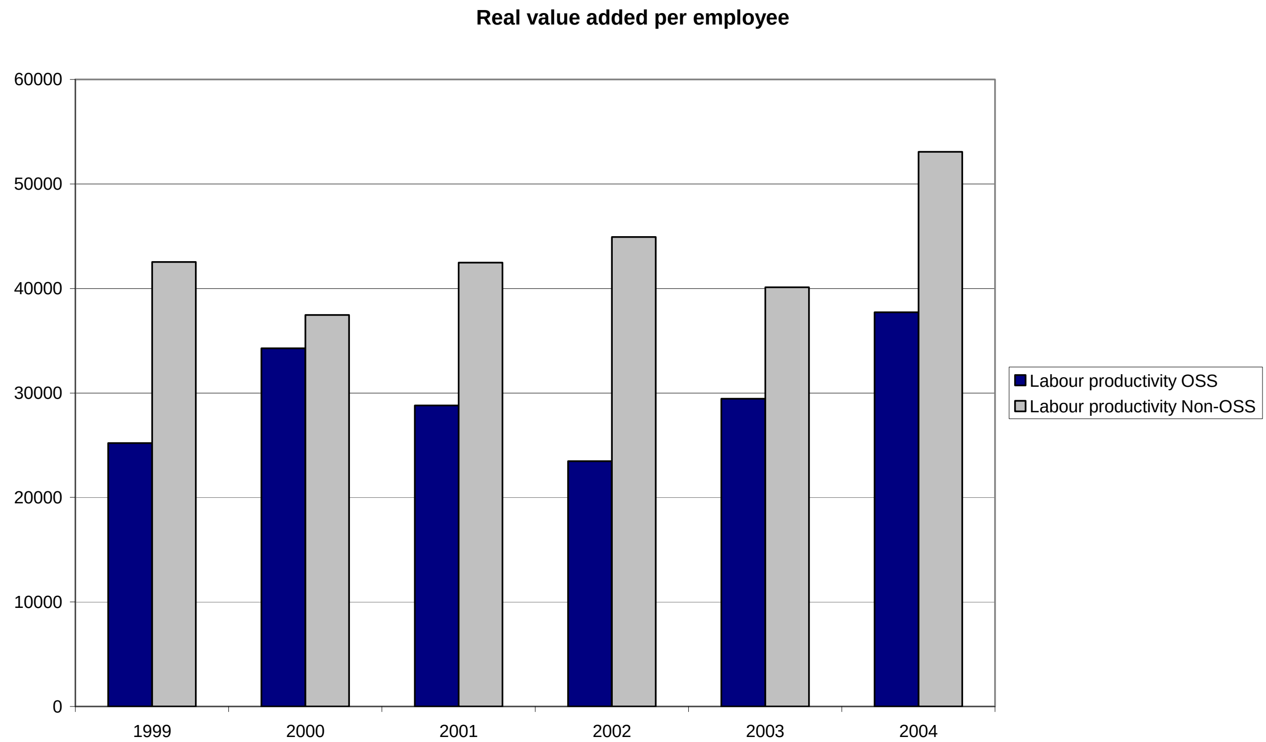
The primary interest of this study relates to the statistical significance of the use of OSS supply strategies (variable OS_BMODEL) and its impacts in the estimated labour productivity model. It has been suggested that one of the major motivations why software companies are interested in joining the OSS mode of development is that OSS communities provide them with external software development resources that replace (at least in part) the internal programming workforce within the firms, as well as other major activities, such as software testing and documentation. In other words, firms adopt the OSS business model to substitute part of their labour inputs by source code that is developed at no cost by the OSS community members. In addition, firms may re-organize their activities and resources more efficiently around distribution of OSS to complement their own core solutions and services, rather than produce the necessary software in-house. If this case proves to happen, adoption of an OSS-based business model should be positively correlated with labour productivity, thereby increasing the labour productivity in those firms. On the other hand, if a firm merely develops software that it delivers under an OSS license and fails to adapt its activities and resources, the OSS mode of development may prove to have negative impact on the firm's value added and would negatively affect its labour productivity.

The dependent variable of the estimated model, labour productivity (variable ADDVAL), represents the firm's real value added per employee. Figure 1 presents the average labour productivity in OSS- and non-OSS software firms[5] between 1999 and 2004. The real value added per employee in the sampled companies varies a lot, between 25000 and over 50000

[5] The term "OSS firm" means that the firm not only uses but also supplies OSS solutions, whereas the term "non-OSS firm" is used to describe companies that merely provide proprietary software solutions.

Euros. Figure 1 suggests that there has been an increase, despite of a temporarily decline in the early 2000, in the Finnish software firms' labour productivity from 1999 to 2003. The overall result suggests that during this period OSS companies were, on average, less productive than non-OSS firms.

Figure 1. Labour productivity: OSS vs. non-OSS firms



We also aim at shedding light on the productivity of the OSS firms before and after the adoption of the OSS business model to answer the question whether the labour productivity of OSS firms have changed due to the adoption of the new open modes of business practices. Furthermore, we are interested in the relationship between the different OSS-business model types and labour productivity. The idea here is to investigate whether and which modes of OSS business practices provide the greatest efficiency gains for the software firms. We explored the productivity implications of the three OSS-based strategies: 1) *Complementary service provision,* 2) *Adapting pre-existing OSS to suit customers' needs or* i*ntegrating OSS* *to the new solutions* that are released under the OSS licenses, 3) Designing and developing *new OSS* solutions *from the scratch to the market or on order to customers.* The respondents of our questionnaire evaluated the importance of each strategy by choosing from three options: “not important”, “nice to have” and “very important”. We coded the three respective dummy variables (VARIABLE OSB_SERV, OSB_USE and OSB_OFFER) 0 if firm reported that the strategy was “not important” and 1 otherwise, indicating that the strategy was actively used by a company. The reported data indicate that firms were less often harvesting the output of the open source community – i.e. employed strategies based on the use of the pre-existing OSS code – than used OSS licenses for their own software products that were either developed on order for customers or from the scratch to the market.

All of the above OSS supply based strategies potentially provide labour productivity gains for the firms. Services that are complementary to the freely-offered OSS products have an important role in OSS-based strategies. OSS producers rely on the distribution of free products, while they generate their revenues by provision of services, such as implementation, customization and development of special software features. Complementary service providers may avoid in-house development of software complementing their own supply, as well as the adapters of strategy ii) using pre-existing code as part of their own software solutions. The firms developing their own OSS products from scratch or on order may succeed in attracting developers outside the firm boundaries to (i.e. the OSS community) to the development of the firm’s software thus reducing its labor costs.

4. Empirical model and results

We used a random effects model for estimating labour productivity:

$$\ln(LP)_{it} = \alpha_0 + \alpha_1 \ln(K/L)_{it} + \alpha_2 OS\_BMODEL + \alpha_x X_{it} + u_i + \varepsilon_{it} \ ,$$

where *LP* denotes *labour productivity* (i.e. real value added per employee), (*K/L*) is the *real value of physical capital per employee,* and *X* is the vector of other *firm-specific characteristics* (see Appendix A for the list of the explanatory variables). The random variation is captured by the two-part error term structure of the standard random effects model: $u_i + \varepsilon_{it}$.

As our dataset is limited only to companies from one country and, further, it is restricted to a single industrial sector of computer and related activities (ISIC Rev. 3 class 72), we avoid some problems that may result from comparing labour productivity of firms across different industries and nations (e.g. due to heterogeneity in factors, it is difficult to control in estimations factors as cross-country variance in standard weekly working hours). Nonetheless, a potential source for biased estimation results of the relationship between a firm's business model and its productivity may result from the mix of service- and production-oriented software companies in our sample, i.e. the productivity differences between service and manufacturing firms may not be related to the efficiency of firms but rather to the inherent nature of their business. We control for pure service providers by the dummy variable SERVICES that takes value 1 if a firm provides only software services and 0 otherwise.[6]

We also took into account potential endogeneity of the OSS business model choice. We estimated a treatment-effects model with the endogenous OS_BMODEL variable[7] using pooled data, with the specification of standard errors to be robust to both heteroscedasticity and serial correlation. Table 1 presents the estimation results of the models.

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[6] We also estimated a model that excludes companies that provide merely services. However, this model did not significantly affect the results of the estimation.

[7] The instrumental variables for the OSBUSE include log of firm age, its number of employees, variables SERVICES, EDUC and UNICITY, and the annual dummy variables. These variables were chosen based on our previous modeling and estimations of the models for firm's adoption of the OSS business model.

*Table 1. Estimation results for the random effects model and treatment-effects model for labour productivity (whole sample)**

Variable	**RE model**	**Treatment-effects model**
Constant	242.14 (1.150)	-75.419 (-0.680)
OS_BMODEL	-0.440 (-3.34)	-1.267 (-3.860)
K/L	0.183 (3.690)	0.156 (3.970)
FOREIGN_OWN	0.852 (2.270)	0.836 (5.800)
SERVICES	0.033 (0.110)	0.014 (-0.100)
EDUC	0.011 (0.310)	0.039 (2.280)
ESTABL_YEAR	-30.79 (-1.11)	11.071 (0.760)
UNICITY	0.517 (2.250)	0.613 (4.990)
Y00	-0.127 (-1.21)	-0.151 (-0.960)
Y01	0.061 (0.590)	0.102 (0.680)
Y02	0.048 (0.470)	0.030 (0.190)
Y03	0.221 (2.20)	0.290 (2.120)
Y04	0.450 (4.34)	0.463 (2.890)
RHO		0.646 (2.020)
Number of observations	288	287
R-square/log-likelihood	R-square: 0.29	Log-likehood: -431.80
Hausman test	Test of H0:RE vs. FE: P-value = .019	
Wald test of indep. eqns.		Test of H0: RHO=0 P-value:0.043

* T-values in paranthesis

The dummy variable measuring whether the firm has adopted an OSS business model or offers the OSS solutions has a negative and statistically significant coefficient in both of the estimated models. Hence, the software producers included in our sample that adopted the OSS-based business model had lower labour productivity, on average, than other companies that operate under the mode of proprietary software development. This finding is significant and important for the decisions of firms to engage in OSS production and provision as their business strategy. Various conceptual studies suggest that firms that choose the OSS mode of development for their products enjoy the advantages of economies of scale by attracting vast online communities of developers and coupling their skills with their own human and technical resources. Thereby, software development costs can substantially decrease by sharing the development efforts with a community of volunteers in a "private-collective" innovation model (see, for example, Von Hippel and Von Krogh, 2003). This study presents quite contradicting findings, based on empirical data, and suggests that the productivity of firms that implement the OSS mode of development is inferior to that of firms producing proprietary software.[8]

Next, the analysis was restricted to the companies that have adopted an OSS-based business model for investigating two questions, whether the labour productivity of OSS firms have changed due to the adoption of the OSS supply strategies and which OSS business practices, if any, enhance labour productivity.

Table 2 shows that the estimated coefficient of variable OS_BMODEL is negative but not statistically significant indicating that there has not been substantial change in the labour productivity of the OSS firms due to the adoption of the OSS business model. This further hints, given our empirical finding that the OSS business model users have significantly lower

[8] We also estimated a model treating the OSS business model choice as an endogenous choice variable of the firms. This didn't significantly affect the estimation results: the conclusions are similar to the ones presented in this paper.

Table 2. Estimation results for the random effects model for labour productivity (OSS-firms)

Variable	**RE model**	**RE model**
Constant	-384,874 (-0,59)	-671,122 (-0,99)
OS_BMODEL	-0,361 (-1.77)	-0,324 (-1.40)
K/L	0,382 (2,71)	0,633 (3,70)
FOREIGN_OWN	1,489 (1,96)	0,621 (0,88)
SERVICES	-0,484 (-0,87)	0,101 (0,15)
EDUC	-0,184 (-0,54)	0,135 (0,28)
ESTABL_YEAR	51,387 (0,60)	88,745 (1,00)
UNICITY	0,957 (1,73)	0,937 (1,71)
OSB_SERV		-0,381 (-0,96)
OSB_USE		1,683 (3,19)
OSB_OFFER		-0,552 (-0,74)
Y00	-0,183 (-0,83)	-0,272 (-1,06)
Y01	0,286 (1,26)	0,048 (0,18)
Y02	0,112 (0,51)	-0,080 (-0,30)
Y03	0,361 (1,59)	0,210 (0,80)
Y04	0,553 (2,29)	0,341 (1,18)
Number of observations	96	83
R-square	0,46	0,66
Hausman test	H0:RE vs. FE: P-value= .87	H0:RE vs. FE: P-value = .99

labour productivity than software firms supplying merely proprietary products, that the OSS firms were possibly also at the time of their adoption of the OSS supply business strategy less productive than other companies.

The dummy variables for the business strategies involving complementary service provision (OSB_SERV) and the development of the OSS solutions on order or from scratch to the market (OSB_OFFER) are not statistically significantly related to firm-level labour productivity. This finding suggests that companies that produce and distribute their own software solutions under the OSS licenses have not obtained notable labour saving contributions from the OSS community compared to those OSS companies that have decided not to launch their own products with the OSS licenses.

The variable OSB_USE, instead, has a positive and statistically significant coefficient. It seems that, indeed, the benefits from the OSS code or software extracted from the OSS community have been sufficiently large to produce statistically significant difference in labour productivity between the adopters and non-adopters of this OSS strategy. This empirical finding indicates that the software firms that have used pre-existed OSS in their products have made substantial savings in the labour-intensive development of new software products due to the code produced and made available by the OSS community.

The estimation results concerning the relationship between the different OSS business model types and labour productivity are rather intriguing. Unfortunately, our data do not allow us to undertake further analyses which could clearly indicate the underlying reasons for the links between the production and supply of OSS solutions and labour productivity (e.g. variables describing the organization of software development in the firm, knowledge exchange between firm developers and community programmers and their direction, the management and efficiency of firm developers, etc.).

5. Discussion

Measuring the productivity of software producing firms is a difficult task that exemplifies some of the issues surrounding the measurements of performance of IT firms and their interpretation through 'standard' economic prisms. The intangible characteristics of information technology goods, and most-likely those of software products, have initiated the *productivity paradox*, which illustrates the theoretical and practical problems associated with measuring productivity in the context of software development and use, when Nobel laureate in economics Robert Solow stated that "we see the computers everywhere but in the productivity statistics" (Boroughs et. al., 1990).[9] Further, due to the intrinsic characteristics of software as both technical applications and sets of text-based instructions and due to strong interdependence between segments of the source code and reusability of part of them in different software products, measuring productivity of software producers in terms of e.g. the number of code-lines or programmed modules creates considerable hardships and can even produce misleading interpretations, as relatively short computer programs can produce substantial commercial and innovative value to their producers and users. Our study takes a somewhat different standpoint by defining productivity of software firms in terms of the economic value that they derive from producing and distributing software applications. Labour productivity (variable LP) is measured by the real value added from software development and distribution per employee.

The findings of the first model clearly indicate that software firms that have chosen to apply the OSS business model had lower labour productivity than other companies. Those findings are rather interesting as a part of the recent literature on the use of OSS business models highlights the potential benefits of firms applying them (see e.g. Bonnacorsi and Rossi, 2003,

[9] See also Brynjolfsson and Hitt (1998), Bresnahan et. al. (1999) and Sichel (1999) for overview of issues associated with measuring productivity in ICT.

Harhoff et. al., 2003 and Henkel, 2006), while there is a volume of studies on their potential caveats (e.g. Goode, 2005). It further seems, given our estimation results, that the companies that are a lower productive type have adopted the OSS business model as a means to enhance their competitiveness.

One possible explanation for our findings is that the productivity gains from the OSS business model use have not yet materialized during the sampled time period, the years 1999-2004, if the firms were not yet completely adjusted to the new business model. It is well-known that the implementation of a new technology or an innovative business model may produce negative economic effects at the firm level in the short-run before the organization has adjusted its work practices to fully utilize the new technology (David, 1990; Bresnahan et. al., 2002; Brynjolfsson and Hitt, 2003). Additionally, including the OSS licensed software solutions in the line of firm’s products does not immediately or directly increase its revenues but may instead decrease it, at least temporarily, if the OSS products merely substitute the previously produced software

The findings of the second model suggest that firms using the OSS business model indeed utilize the OSS community as an external software development unit for their own products. OSS production (partially) replaces the internal development efforts of firms and reduces their own labour inputs that are needed to complete the development of their software goods. For instance, if software were licensed with restrictions to enable its commercial utilization, the firm may use those features that were programmed by the community members to further develop and to release proprietary licensed versions for profit making.

6. Conclusions

The primary findings of our study suggest that software firms that adopt the OSS-based business model are notably less productive than companies that merely offer proprietary software solutions. Our estimation results further show that the OSS business model adopters have not become notably less productive after beginning to supply OSS. Therefore, its seems that not the use of the OSS business model as such has reduced the OSS firms' labour productivity but the firms that employed the OSS business model during the sampled years were, on average, of lower labour productivity type. Though the OSS business model use has not substantially improved the performance of software firms, we find that the OSS business model adopters strategically using the source code made available by the OSS community as part of their new software products, have performed better in terms of labour productivity than other adopters of the OSS business model.

Our estimation results refer only to the supply of software applications. Do firms that merely use OSS solutions – probably some of the sampled proprietary software suppliers - but not supply them perform better or worse than organizations that apply proprietary applications is a worthwhile question that can further be developed in various directions, e.g. elaboration of the links between individuals, organizations and online communities and the alignment (or the tradeoff) between the productivity of software developers in organizations and their contribution to OSS projects.

The study contributes to the growing economic literature concerning the software developing firms and OSS communities. The new insights provided by our study opens new venues for future research regarding the links between the open, the proprietary and the *hybrid* (i.e. partially open and partially proprietary) modes of software development and the resulting productivity of firms operating under each regime. The productivity of software developers is likely to be affected by the internal organization of the programming process within firms under each development model, the governance structure of the joint development project and the roles and position of the firm vs. those of the OSS community, the types of activities deligated to community members and the strength of links between firms and OSS communities in joint software projects.

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Appendix A: Description of the Variables

Variable name	**Variable description**	**Mean**	**Std Dev**
Dependent variable: LP	Log(real value added*/number of employees)	27769,09	22523,18
Explanatory variables:			
OS_BMODEL	Dummy variable that takes value 1 if a firm employs an OSS-based business model at given year (i.e. supplies OSS solutions), 0 otherwise.	0,240	0,427
K/L	Log (real value of physical capital per employee)	9,519	1,476
FOREIGN_OWN	Dummy variable that takes value 1 if a firm is foreign-owned, 0 otherwise.	0,065	0,247
SERVICES	Dummy variable that takes value 1 if a firm provides only software services, and 0 otherwise	0,090	0,287
EDUC	Log share of employees having at least university degree.	-1,170	2,395
ESTABL_YEAR	Log the year firm was established.	7,597	0,003
UNICITY	Dummy variable that takes value 1 if a firm is located to university city, 0 otherwise.	0,823	0,382
OSB_SERV	Dummy variable that takes value 1 if a firm provides complementary services to OSS, 0 otherwise.	0,513	0,501
OSB_USE	Dummy variable that takes value 1 if a firm adapts pre-existing OSS to suit customers' needs or integrates OSS to the new solutions that are released under the OSS licenses, 0 otherwise.	0,707	0,457
OSB_OFFER	Dummy variable that takes value 1 if a firm designs and develops new OSS solutions from the scratch to the market or on order to customers, 0 otherwise.	0,812	0,392
Y00	Dummy variable that takes value 1 for year 2000, 0 otherwise.	0,150	0,358
Y01	Dummy variable that takes value 1 for year 2001, 0 otherwise.	0,159	0,366
Y02	Dummy variable that takes value 1 for year 2002, 0 otherwise.	0,175	0,380
Y03	Dummy variable that takes value 1 for year 2003, 0 otherwise.	0,191	0,393
Y04	Dummy variable that takes value 1 for year 2004, 0 otherwise.	0,169	0,375

* We obtained real valued by dividing value added by the average of three US producer price index (PPI) categories for software – i) applications software and computer games, ii) pre-packaged software and iii) maintenance, documentation, training, and other software services -deflated by the general price changes in Finland. In case of firms that provided only services, we used for calculating PPI only category iii), and in case of companies that provided only software products, the average of categories i) and ii).

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