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Research Paper

The Impact of Open Source Software Commercialization on Firm Value

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ABSTRACT Vendors of proprietary software products are increasingly moving to business models inspired by open source software (OSS). This study investigates sources of heterogeneity in value appropriation associated with commercializing OSS. Specifically, I suggest that the relationship between a firm's OSS releases and its value depends critically on its stocks of protection mechanisms for intellectual property rights, such as software patents and software trademarks. I find that while software patent stocks positively affect the relationship between a firm's OSS product portfolio and its value, software trademark stocks have a negative effect on this relationship.

KEY WORDS: Open source software, intellectual property rights, firm value

JEL Classification: O31, O34, L86

1. Introduction

Open source software (OSS) has drawn attention from diverse academic fields, following the enormous success of well-known OSS projects such as Linux and Apache. Several studies have centered mostly on the motives driving users and developers to contribute to OSS projects (Lerner and Tirole 2002; Lakhani and Wolf 2005), how innovation processes function (Lakhani and von Hippel 2003) and governance issues in OSS communities (Shah 2006; O'Mahony and Ferraro 2007). Since becoming commercially viable (Fitzgerald 2006), another line of research on OSS has focused on for-profit firms collaborating with OSS communities (Dahlander and Magnusson 2005; Bonaccorsi, Giannangeli, and Rossi 2006), the intellectual property right (IPR) protection mechanisms firms use to ensure their returns from open business models (Lerner and Tirole 2005; Henkel 2006) and the competitive dynamics introduced by OSS (Bonaccorsi and Rossi 2003; West 2003).

Although the widespread adoption and acceptance of OSS has been attributed to its complementarity to proprietary developments (Bonaccorsi and Rossi 2003; Schmidt and

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Schnitzer 2003; West 2003) and though its potential benefits for the engaging parties have largely been identified (Henkel 2006), the financial benefits OSS commercialization might bring to a for-profit firm still lack empirical evidence. To the best of my knowledge, only a few studies have investigated the effect of firms' engagement in OSS communities on their performance. Using cross-sectional survey data, Stam (2009) finds an inverted U-shaped relationship in his study, which explores the link between firms' technical community participation and their innovative/financial performance. Alexy and George (2013) report systematic links between commercial engagement in OSS and firm value conditional on the legitimacy of the firm, as perceived by the capital market. Although these studies, at first glance, highlight a significant relationship between firms' engagement in OSS communities and their performances in certain contexts, further investigation is necessary to understand whether commercialization of OSS products generates financial value for firms.

Fosfuri, Giarratana, and Luzzi (2008) focus on the heterogeneity among firms' endowments of protection mechanisms for IPR to explain their decisions to incorporate OSS into commercial product portfolios. Their results suggest that variations in pre-existing stocks of protection mechanisms for IPR—namely, patents and trademarks—help explain why some firms take more commercial actions within the OSS paradigm than others. In this study, I aim to extend recent research by focusing on performance consequences of OSS commercialization and by assessing the moderating role of IPR protection mechanisms on the relationship between firm value and OSS commercialization. I explain the mechanisms through which IPRs may affect the aforementioned relationship and provide empirical evidence in support. In doing so, I use Tobin's q to proxy for firm value and analyze panel data of 70 companies covering a seven year period from 2003 to 2009. I argue that the potential for appropriating returns from commercializing OSS products depends critically on firms' stocks of software patents and trademarks. The findings are twofold. First, I show that OSS commercialization cannot result in financial benefits to a firm without the right set of IPR stocks. Second, software patent and trademark stocks interact with the OSS portfolio, such that software trademarks have a negative effect on the relationship between firm value and OSS commercialization, while software patent stocks have a positive effect on this relationship.

In the next section, I present the theoretical background for the empirical analysis, before describing the data and identifying the variables in my estimations. In the empirical section, I present the results. Finally, I offer a brief discussion of the findings and conclude.

2. The Role of Firms' IPR Protection Mechanisms

Literature on the protection of valuable knowledge is extensive (Rumelt 1984; Barney 1986). Traditional theory in strategy and innovation management suggests that a company generates, develops and commercializes its own ideas and that managers' key challenge is retaining the knowledge within the firm to appropriate returns (Teece 1986). On the other hand, open innovation, which has rapidly come to the fore as a new paradigm for corporate innovation, focuses on identifying, exploiting and integrating external knowledge into internal research-and-development activities (West and Gallagher 2006). Firms that adopt the open innovation model integrate these external sources (e.g., customers, suppliers, competitors and universities) into their internal innovation processes and competitive strategy to sustain the ability to introduce new products to the market successfully (Chesbrough 2003). OSS, which is freely available to all parties that accept the licensing terms of the software, is the outcome of such an open innovation model, in which companies collaborate with communities of volunteer developers. Given the open nature of OSS, which tends to make them a public good (Lerner and Tirole 2002), firms face the challenge of reaping the benefits from it. Appropriability regimes that use legal mechanisms of protection help firms advance their capabilities to retain created value in this specific setting, due to the modular architecture of the OSS code, which can be combined with proprietary developments (Teece 1986, 1998).

How do firms' endowments of IPR affect the relationship between commercialization of OSS and performance? To address this question, I investigate the IPR protection mechanisms that are crucial for appropriating value to a firm that commercializes OSS. Studies of OSS and associated appropriation regimes suggest several protection methods, ranging from licensing (Behlendorf 1999; Hecker 1999; Raymond 1999) to standard protections, such as copyright, secrecy, lead time and complementary assets (Feller and Fitzgerald 2002; Dahlander 2005; Fosfuri, Giarratana, and Luzzi 2008). I focus specifically on software patents and trademarks, which are important firm resources that explain the heterogeneity in firms' decisions to engage in OSS commercialization (Fosfuri, Giarratana, and Luzzi 2008). Although copyrights provide an alternative IPR mechanism for software, my aim is to investigate whether firms' efforts to build an open source-based strategy brings the necessity to build strategic IPR portfolios, rather than questioning the power of copyrights, patents or trademarks to protect the underlying technology per se. Building strategic patent/trademark portfolios dependent on a firm's short-term goals and long-term objectives is a debated issue in the domain of strategic management (Hall 1992; Mendonça, Pereira, and Godinho 2004; Blind, Cremers, and Mueller 2009). Yet, within the context of OSS, these portfolios play a critical role in defining the conditions under which commercialization can be most beneficial.

2.1 Software Patents

Hall and Ziedonis (2001) suggest that patents are important IPR mechanisms for firms not only because they operate as effective appropriation mechanisms but also because they confer negotiation power on technologies over external sources. Alexy and Reitzig (2013) argue that firms that pursue a private-collective model of innovation continue acquiring patents mainly to gain de facto control of a technology among several proprietary competitors within the context of OSS. Focusing on appropriation mechanisms needed to profit from OSS commercialization, Mann (2006) argues that corporate members of OSS communities often continue to invest heavily in software patents, primarily to protect themselves from the threat of litigation. Patent rights are imperfect in the sense that they transfer the rights to exclude others from using the technology but do not transfer the usage rights of the technology to the patent holder (Gans and Stern 2010). Thus, the use of a large patent portfolio for generating value from the commercialization of a complex technology, such as in the case of OSS, can be substantial (Levin et al. 1987). Even if the software patent in such a portfolio does not provide direct protection for what is being released per se, it may enable the firm to capture the value created through other channels by establishing the necessary conditions—for example, by boosting profits on a complementary segment in proprietary form (Lerner and Tirole 2002) or by displacing another party from the value chain (Hardy 2013). Fosfuri, Giarratana, and Luzzi (2008) argue that having a large portfolio of software patents is beneficial for OSS commercialization for three reasons: potential complementarity between the patented software and commercial OSS products, control over future improvements of an OSS project and protection against litigation.

In contrast, Shah (2006) suggests that tight control of IPR discourages participation in OSS projects that rely mainly on volunteer programmers. According to this viewpoint, the concept of extracting financial benefits from jointly developed software contradicts the core values of the OSS movement and thus creates a feeling of "repugnance" (Gans and Stern 2010) that may harm community members' willingness to participate free of charge. However, it is important to distinguish between creation of OSS and its commercialization packaged into proprietary products or services (Teece 1998). Although implementation help by volunteer developers is important for the advancement of the project, firms that aim to develop a commercial product jointly with a community do so mainly to receive design help from their potential future customers (Goldman and Gabriel 2005). Thus, firms are more concerned about attracting potential users, rather than programmers, to the communities in which they participate, with the goal to develop a commercial OSS product. Thus, losing participation from tight appropriability is not an issue for community-based developments whose principal contributors are potential users of the outcome product.

I argue that large software patent stocks may boost the returns generated from the commercialization of OSS and lead to superior firm value as measured by Tobin's q for four reasons. First, large stocks operate as strategic tools to sell complementary products/services along with OSS developments and to help firms expand complementary technologies into proprietary domains that play key roles in their sustained competitive advantage equation. Second, they enable firms to sell products/services complementary to their proprietary offerings, thereby potentially displacing other parties in the value chain and freeing up consumer resources. Third, they help firms retain control over future improvements of the software, which is widely accessible through the development platform. Fourth, they allow the firm to avoid holdups and litigation threats by technology suppliers that own relevant patents.

Hypothesis 1: Large software patent stocks positively affect the relationship between a firm's OSS product portfolio and its firm value, such that as the number of software patents increases, the relationship becomes stronger.

2.2 Software Trademarks

In contrast with the extensive debate on the value of patents in classical incentive theory (Hall and MacGarvie 2010), trademarks have only recently received attention (Mendonça, Pereira, and Godinho 2004). A trademark refers to any word, symbol or name used by a manufacturer to distinguish its goods from those sold by others by leveraging its owner's reputation. In a previous study, O'Mahony (2003) argues that trademarks may foster volunteer participation in community-based OSS projects because they help build a strong brand name and reputation. Linux, Apache and Debian have all trademarked their names, both for differentiation purposes and to prevent proprietary appropriations of their OSS code (O'Mahony 2003). All these exemplar development projects with strong brand names receive support largely by donations through several non-profit organizations and rely strongly on codebase developed by volunteer participants. Today, however, as OSS has transformed into a commercially viable form (Fitzgerald 2006), firms engage in community-based projects mainly with the intent to receive design help and new product functionality ideas from potential users rather than receiving implementation help from volunteer developers (Riggs and von Hippel 1994; Goldman and Gabriel 2005). For this reason, investing in a strong brand name to gain implementation help from volunteer developers is not a relevant strategy for profit-oriented firms endowed with skilled developers being paid for the job.

I suggest that investing in trademarks will have a negative effect on the relationship between OSS portfolio and firm value for two reasons. First, investing in a brand name and reputation is not a compatible strategy for firms that want to commercialize OSS products. OSS is a collaborative mode of software development that targets consumers who want cost-saving solutions (von Hippel and von Krogh 2003), while trademark registration is an investment tailored to proprietary domains for the purpose of increasing consumers' willingness to pay a premium for product quality (Fosfuri, Giarratana, and Luzzi 2008). Research suggests that product innovation is illegitimate because it clashes with established routines and shared understandings within the firm (Dougherty and Heller 1994). Alexy and George (2013) provide support for this argument with empirical evidence from the domain of OSS and suggest that firms should act in a way that complies with their current innovation strategy to receive benefits. For a firm commercializing OSS, investing in a brand name and reputation—in other words, registering trademarks—may send mixed signals to its customers and damage its overall position in the marketplace. However, the illegitimacy discounts arising from the registration of software trademarks may not be experienced by firms that hold considerable software patent stocks. Patent rights are imperfect property rights and are commonly used as strategic tools (Gans and Stern 2010). OSS is a complex technology, and it is not possible for firms to protect it or increase its commercial importance with a limited number of patent rights (Levin et al. 1987; Mann 2006).

Second, investing in trademarks may lead to substantial losses for the company as a result of credible holdup threats. OSS incorporates high modularity, which makes it possible for firms to generate profits (Lerner and Tirole 2002). However, such complex technologies are prone to generating patent thickets (Hall and Ziedonis 2001), which refer to dense networks of overlapping IPRs from which a company needs to escape to be able to commercialize the new technology (Shapiro 2001). Such patent thickets create transaction costs and reduce the demand for the new technology because of the perceived likelihood of being held up by rivals that own relevant patents (Gans and Stern 2010). Innovators may not be able to commercialize the technology under construction if they depend on access to single IPRs (Shapiro 2001). Firms that cannot secure access to the underlying technology because of strong patenting activity and the high threat of litigation existing in the OSS domain may be reluctant to invest in complementary assets in the form of brand names and reputation. As Gambardella, Giuri, and Luzzi (2007) suggest, a broader market for technologies is restricted by transaction costs. That is because investments in complementary assets (e.g., brands) will generate losses if the new technology cannot be commercialized. Thus, investing in complementary assets in the form of brand names and reputation—in other words, registering for software trademarks—should have a negative effect on the relationship between commercialization of OSS and firm value, as measured by Tobin's *q*.

Hypothesis 2: Large software trademarks stocks negatively affect the relationship between a firm's OSS product portfolio and its firm value, such that as the level of software trademark stocks increases, the relationship becomes weaker.

3. Data and Descriptive Statistics

I undertake an empirical analysis with a novel data-set in which I aimed to include all companies operating in software-related industries[1] from the *Fortune* Global 500 list. Although the initial data contained information on 83 companies from 2003 to 2009, I excluded the firms that lacked financial information during the period under study.[2] Although the period of analysis is from 2003 to 2009, I began collecting data from 1999. All the main variables of interest are cumulative numbers, and 4 years' worth of batching should provide more reliable results. With a final sample of 490 firm-year (70 firms $\times$ 7 years) observations, I explore the performance consequences of OSS commercialization under heterogeneous regimes of IPR protection.[3]

I extracted financial data from the COMPUSTAT database, including market values, total assets, total debt and preferred stock. Tobin's *q* serves as the dependent variable, which offers a forward-looking proxy for firm value. When the value of Tobin's *q* is greater than 1, the outlook for the firm's growth opportunities is considered positive. Although this measure generally serves to proxy for value intangible assets, such as patents or trademarks, it also can reflect market hype or speculation, as is common in technology markets. As Lerner and Tirole (2002) discuss, releasing OSS is usually a strategic move (e.g., to weaken a competitor). OSS commercialization and the use of IPR mechanisms for revenue strategies should be differentiated as a firm's effort to build a new business model that brings benefits in the long run, rather than as a strategy to release a proprietary software product with the expectation of direct monetization per se. Releasing source code signals technical excellence and goodwill (Henkel 2006) that originates from firms' intellectual capital, which can be captured by Tobin's *q*. I calculate a modified version of Tobin's *q* using the following formula by Chung and Pruitt (1994):

$$\text{Approximate } q = \frac{\text{MVE} + \text{PS} + \text{DEBT}}{\text{TA}},$$

where MVE is the product of common shares outstanding and the month-end price that corresponds to the period end date, PS is the liquidating value of preferred stock, DEBT is the sum of total long-term debt and debt in current liabilities, and TA is the book value of total assets. Approximate *q* explains 96.6 per cent of the variability of Tobin's original formulation (Lindenberg and Ross 1981), which is complex in its calculation and requires access to multiple, restricted databases (Chung and Pruitt 1994). The reason for using approximate *q* is its simplicity in calculation using basic financial and accounting information through a publicly available database, such as COMPUSTAT. Nonetheless, the approximate *q* has

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[1] These industries include Electronics & Electrical Equipment, Computers & Office Equipment, Computer Software, Telecommunications and Semiconductors.

[2] The excluded firms are those that did not report financial information in some of the years during the period of analysis. This could have been due to a corporate event, such as an acquisition, filing bankruptcy or spinoff.

[3] Of the 70 firms in the sample, 28 introduced at least one OSS product to the market during the 7-year period. Considering that commercialization of OSS is a rising trend but not yet a common practice, the sample size is within an acceptable range. I identified all the firms from the *Fortune* Global 500 list that operate in the software industry at some level, even if the principal sector in which they operate differed. In this respect, the sample is comprehensive.

broad usage in accounting and finance (Chung and Pruitt 1994). Firm size, as measured by the number of employees, is retrieved from COMPUSTAT as well.

I next searched for press articles that reported a "product announcement", "new software release", or "software evaluation" in the software sector (Standard Industrial Classification code 7372) and product introduction event category (event code 336) in the PROMT database. Reports of product introductions that included the phrases "open source" or "Linux" indicated possible OSS product introductions. I read the text of each article in the possible OSS product introductions set to distinguish articles that clearly referred to an open source product introduction. Next, I computed the cumulative number of OSS product announcements to proxy for a firm's OSS product portfolio. Specifically, I summed the number of OSS products introduced to the market starting from 1999 at a 15 per cent annual discount rate[4] using the following formula:

$$\mathrm{OssPortfolio}_t = (\mathrm{Oss}_t + \mathrm{Oss}_{t-1} \times (0.85) + \mathrm{Oss}_{t-2} \times (0.85)^2 + \cdots + \mathrm{Oss}_{1999} \times (0.85)^{t-1999}),$$

where Oss_t is the number of OSS introductions in year *t*.

The information on patents and trademarks comes from the U.S. Patent and Trademark Office database. I searched for all patents granted to a given firm in each year (1999–2009). After gathering data about all patents, I identified software patents using Graham and Mowery's (2003) algorithm, according to which certain international classification classes—such as "Electric Digital Data Processing" (G06F), "Recognition of Data; Presentation of Data; Record Carriers; Handling Record Carriers" (G06K), and "Electric Communication Technique" (H04L)—represent software patents.[5] These classes were selected after examination of the patents of six major U.S. software producers (1995 revenues; Microsoft, Adobe, Novell, Autodesk, Intuit, and Symantec) between 1984 and 1995. Patents in the three selected classes account for 57 per cent of the patents assigned to the 100 largest firms in the software industry (Hall and MacGarvie 2010). Furthermore, trends in these classes represent overall software patenting activity because they include areas in which patenting grew rapidly in the late twentieth century.

Hall and MacGarvie (2010) compare three different classification methods to identify software patents with a sample of more than 1000 manually identified software patents by John Allison (Allison and Lemley 2000; Allison and Tiller 2003). These three approaches to determine software patents are also used by Graham and Mowery (2003), Bessen and Hunt (2007) and Hall and MacGarvie (2010). Hall and MacGarvie (2010) provide a new approach that combines the three approaches and stress the superiority of the combined method. Graham and Mowery (2003) approach does well in terms of Type II errors (detecting a patent as a software patent when it is not), which is approximately 5 per cent. However, it is not as successful in the case of Type I errors (overlooking a software patent when it should have been identified), which is 40 per cent. Hall and MacGarvie's (2010) proposed combined

[4] The Bureau of Industry Economics (1994) adopts a discount rate of 15 per cent when assessing private returns to patent holders because the value of patents tends to fall over time. I follow a similar logic for assessing private returns from OSS commericalization because the value associated with older products will diminish over time as technology evolves and enhanced products enter the market.

[5] The groups included are as follows: G06F 3, 5, 7, 9, 11, 12, 13, 15; G06K 9, 15 and H04L 9.

method does somewhat better in terms of Type I errors (27 per cent) and almost the same in terms of Type II errors (5 per cent). Thus, applying the proposed combined method likely would not have changed my results, because the software patents I capture are representative of the actual software patent stocks of a firm. Identifying non-software patents as software patents is more problematic than overlooking some software patents. The last method by Bessen and Hunt (2007), though satisfactory in identifying software patents, identifies a large portion of non-software patents as software patents. Therefore, I preferred using Graham and Mowery (2003) approach to the other two; it is more straightforward and provides robust results.

Using the same source, I also extracted trademark data at the firm level on a yearly basis by searching for all trademarks filed by each firm between 1999 and 2009. To distinguish software trademarks, I applied the search algorithm Fosfuri, Giarratana, and Luzzi (2008) suggest and searched for strings of words in the trademark description text.[6] The strings of words used to distinguish a software trademark include "computer software" or "operating system" or "computer program" or "software algorithm" or "data processing" or "software application". The error percentages are 14.2 and 7.7 for non-software trademarks that were included as software (Type II) and software trademarks that were not detected by the search algorithm (Type I), respectively. I computed the cumulative number of software patents and software trademarks at a 15 per cent annual discount rate in the same way I computed the OSS portfolio.[7] Table 1 provides variable definitions. The descriptive statistics and pairwise correlations for the main variables appear in Table 2.

4. Empirical Analysis and Results

After conducting a Hausman (1978) specification test, I ran a fixed effects model with Tobin's q as the dependent variable to proxy for firm value. I incorporated interaction terms between OssPortfolio and the two variables that correspond to firms' IPR protection mechanisms, SoftwarePatents and SoftwareTrademarks. The full model is as follows:

$$\begin{aligned}\text{Tobins}Q_{it} = {} & \beta_0 + \beta_1\text{OssPortfolio}_{it} + \beta_2\text{SoftwarePatents}_{it} + \beta_3\text{SoftwareTrademarks}_{it} \\ & + \beta_4\text{FirmSize}_{it} + \beta_5\text{FirmAge}_{it} + \beta_6\text{OssPortfolio}_{it} \times \text{SoftwarePatents}_{it} \\ & + \beta_7\text{OssPortfolio}_{it} \times \text{SoftwareTrademarks}_{it} + \alpha_t + \varepsilon_{it},\end{aligned} \tag{1}$$

where the subscripts i and t denote firm and year-specific observations, respectively. The dummy variable α_t indicates year effects. Firm-level characteristics, such as size and age, are also included in the model. I used the natural logarithms of all the variables.

The results from Model 1, with mean-centered interactions in Table 3, reveal that the coefficient for OssPortfolio × SoftwareTrademarks is significantly negative, while that for OssPortfolio × SoftwarePatents is significantly positive. In contrast, the coefficients for the

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[6] See Fosfuri, Giarratana, and Luzzi (2008) for details on the accuracy of the algorithm.

[7] This study focuses on the moderating effect of software trademarks and software patents- and not on the moderating effect of hardware trademarks and hardware patents. As has been discussed in Hypotheses 1 and 2, I expect the relationship between OSS commercialization and Tobin's q to be affected by trademarks/patents through certain mechanisms that are mostly strategic and that can take place exclusively if these trademarks/patents pertain to software domain.

Table 1. Variable definitions

Variable name	Description	Source
Tobins$Q$ (dependent variable)	(Market value + preferred stock + debt)/total assets (log transformed)	COMPUSTAT
OssPortfolio	Σ_{1999}^{t} OSS products calculated for year t at a 15 per cent discount rate (log transformed)	PROMT
SoftwarePatents	Σ_{1999}^{t} software patents calculated for year t at a 15 per cent discount rate (log transformed)	USPTO
SoftwareTrademarks	Σ_{1999}^{t} software trademarks calculated for year t at a 15 per cent discount rate (log transformed)	USPTO
FirmSize	Employees in year t (log transformed)	COMPUSTAT
FirmAge	Age of the firm (log transformed)	COMPUSTAT

Note: USPTO, U.S. Patent and Trademark Office.

direct effects of OssPortfolio, SoftwareTrademarks and SoftwarePatents are not significant. Thus, the findings confirm both Hypotheses 1 and 2. Despite the rising trend in OSS commercialization by for-profit firms, relying solely on an open business model remains too risky in competitive markets. Appropriability mechanisms, such as software patents and software trademarks, appear crucial for firms that are willing to commercialize OSS.

I next estimated a second model to clarify the impact of firms' IPR protection mechanisms on the relationship between OSS product portfolio and firm value. I split the data for firms that commercialize OSS into two, as LowOssPortfolio and HighOssPortfolio, depending on the number of OSS releases of firms. Then, I created the mean-centered interaction terms with the SoftwarePatents and SoftwareTrademarks variables, as previously. Model 2 is as follows:

$$\begin{aligned}\text{Tobins}Q_{it} = {} & \beta_0 + \beta_1 \text{LowOssPortfolio}_{it} + \beta_2 \text{HighOssPortfolio}_{it} + \beta_3 \text{SoftwarePatents}_{it} \\ & + \beta_4 \text{SoftwareTrademarks}_{it} + \beta_5 \text{FirmSize}_{it} + \beta_6 \text{FirmAge}_{it} + \beta_7 \text{LowOssPortfolio}_{it} \\ & \times \text{SoftwarePatents}_{\text{it}} + \beta_8 \text{LowOssPortfolio}_{it} \times \text{SoftwareTrademarks}_{it} \\ & + \beta_9 \text{HighOssPortfolio}_{it} \times \text{SoftwarePatents}_{it} + \beta_{10} \text{HighOssPortfolio}_{it} \\ & \times \text{SoftwareTrademarks}_{it} + \alpha_t + \varepsilon_{it}, \qquad (2)\end{aligned}$$

where the coefficients $\beta_7 - \beta_{10}$ measure the impacts of interactions between firms' OSS portfolios at different levels and their IPR protection mechanisms.

The results of Model 2 indicate that the interaction term between the high levels of OSS portfolio and software patents (HighOssPortfolio × SoftwarePatents) is significantly positive, while that for the interaction between the low levels of OSS portfolio and software patents (LowOssPortfolio × SoftwarePatents) is non-significant.[8] A similar result occurs for the

[8] I split the data into five sub-samples and use the same model to estimate coefficients on the interaction terms. The sub-samples are created using Standard Industry Classification codes for the industries in which firms operate. The five categories through which I aim to proxy for firms' technical expertise in developing software are as follows: *hardware, software, electronics, semiconductors* and *telecommunications.* Although the significance of the coefficients on the interaction terms diminishes at some level, the effects remain the same in terms of directionality. The results suggest that the findings are robust to firms' technical expertise in developing software.

Table 2. Descriptive statistics

	Observations	Mean	SD	Minimum	Maximum	1	2	3	4	5	6
1. Tobins*Q*	490	0.397	0.639	−1.434	2.371	1.000					
2. OssPortfolio	490	0.588	1.050	0	4.208	−0.168	1.000				
3. SoftwarePatents	490	5.442	2.249	0	9.456	−0.014	0.499	1.000			
4. SoftwareTrademarks	490	1.955	1.287	0	5.014	0.117	0.592	0.600	1.000		
5. FirmSize	490	10.145	1.392	6.446	12.895	−0.379	0.275	0.446	0.292	1.000	
6. FirmAge	490	3.639	0.818	1.098	5.069	−0.298	0.040	0.136	0.112	0.434	1.000

Table 3. Fixed effects model

Variables	Baseline	Model 1	Baseline	Model 2
OssPortfolio	0.003 (0.115)	−0.021 (0.122)		
LowOssPortfolio			−0.040 (0.147)	−0.045 (0.160)
HighOssPortfolio			0.003 (0.116)	−0.024 (0.131)
SoftwareTrademarks	0.027 (0.049)	−0.012 (0.054)	0.025 (0.049)	−0.008 (0.055)
SoftwarePatents	0.034 (0.049)	0.067 (0.054)	0.034 (0.049)	0.061 (0.055)
Oss × Sw_Trademarks		−0.151** (0.072)		
Oss × Sw_Patents		0.104** (0.046)		
Low_Oss × Sw_Trademarks				−0.197 (0.123)
High_Oss × Sw_Trademarks				−0.141* (0.076)
Low_Oss × Sw_Patents				0.118 (0.107)
High_Oss × Sw_Patents				0.094* (0.049)
FirmSize	−0.125* (0.070)	−0.132* (0.071)	−0.123* (0.071)	−0.131* (0.071)
FirmAge	−0.131 (0.226)	−0.180 (0.222)	−0.138 (0.224)	−0.195 (0.221)
Year dummies				
_It_2003	0.358*** (0.074)	0.341*** (0.074)	0.353*** (0.075)	0.335*** (0.074)
_It_2004	0.330*** (0.066)	0.323*** (0.066)	0.326*** (0.067)	0.318*** (0.066)
_It_2005	0.347*** (0.059)	0.345*** (0.059)	0.343*** (0.060)	0.341*** (0.059)
_It_2006	0.325*** (0.052)	0.328*** (0.052)	0.322*** (0.052)	0.325*** (0.052)
_It_2007	0.261*** (0.048)	0.264*** (0.048)	0.259*** (0.048)	0.261*** (0.048)
_It_2008	−0.126** (0.053)	−0.125** (0.052)	−0.127** (0.053)	−0.126** (0.052)
Constant	1.931* (1.113)	2.173* (1.130)	1.710 (1.082)	2.226** (1.131)
Observations	490	490	490	490
Adj R^2	0.840	0.842	0.839	0.841
R^2	0.402	0.413	0.402	0.413
Number of firms	70	70	70	70

Note: $^*p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

interaction terms between low and high levels of OSS portfolios and software trademarks, suggesting that high levels of OSS portfolio are largely responsible for the findings. The inclusion of the interaction terms improved the model's explanatory power in both Model 1 and Model 2, as indicated by the adjusted R-square values in Table 3. Thus, while the marginal OSS released in interaction with software patents/software trademarks is associated with significant increases/decreases in Tobin's *q*, the decision of whether to commercialize OSS or not does not seem to have a significant effect without the right set of IPR mechanisms.

Specifically, firms taking more commercial actions while operating according to the OSS paradigm can achieve a higher firm value when they possess IPR protection mechanisms, such as software patents. While commercial OSS releases ensure diffusion and create a marketplace for complementary proprietary products and services, software patents help firm reap benefits. Conversely, firms with large software trademark stocks experience decrements in firm value when they seek to serve their customers with OSS-based solutions. Open source solutions, which require skills for usage and maintenance, may not meet the needs of their established customers, who are willing to pay a premium for a ready-to-use package. Thus, OSS commercialization may cannibalize such firms' existing proprietary lines of business that are highly linked to their brand investments.

Graphical analysis offers a visual explanation of the interactive effect between IPR protection mechanisms and OSS releases. Three values of software trademark stocks, which correspond to the 25th, 50th and 75th percentiles, respectively, were selected as representative of the range of software trademark stocks included in the sample. For OSS portfolio, the representative values correspond to 5th, 25th, 50th, 75th and 95th percentiles.[9] Figure 1 depicts one regression line for each of these software trademark portfolios. The smallest stocks of software trademarks (software trademarks = 25th percentile value) showed a small decrease in Tobin's *q* as OSS portfolio value increases from its value at 5th to 95th percentiles. At a medium level, software trademark stocks (software trademarks = 50th percentile value) showed a rather clearer decrease in Tobin's *q* as OSS portfolio becomes larger. The largest stocks of software trademarks (software trademarks = 75th percentile value) showed a notable decrease in Tobin's *q*, with increasing values of OSS portfolio. Increases in software trademark stocks and OSS portfolio predicted a significant decrease in Tobin's *q*. Furthermore, as Figure 1 shows, as the level of software trademark stocks increases, the relationship becomes stronger. In Figure 2, each regression line can be interpreted as a representative for three different levels of software patent stocks that correspond to the values at 25th, 50th and 75th percentiles. The graph shows that increases in software patent stocks and OSS portfolio predicted a significant increase in Tobin's *q*. Moreover, the statistically significant interaction suggests that this relationship is stronger for firms with larger software patent stocks. These results reflect the importance of aligning OSS commercialization with IPR protection mechanisms. They also imply that an optimal portfolio of IPR protection mechanisms for firms that want to reap the largest benefits from a large portion of OSS portfolio is the one with the large stocks of software patents and relatively small stocks of software trademarks.

To alleviate concerns that the results are being driven by the choice of Tobin's *q* as a measure of performance, I re-ran the analysis using gross profit margin as an alternative dependent variable.[10] The results obtained from Models 1 and 2 using the alternative measure of performance remained unchanged in terms of directionality. However, there were some differences across coefficients on the direct and indirect effects in terms of significance. While OSS portfolio, software trademarks and software patents had a positive, significant effect on performance measured through gross profit margin, the interaction terms created between OSS portfolio and software patents/trademarks were non-significant. As discussed previously, the rationale for using Tobin's *q* is its ability to capture future performance potential. Bharadwaj, Bharadwaj, and Konsynski (1999) report that they use Tobin's *q* as a dependent variable in their study because IT investments contribute to both long-term firm performance and firm intangible value. In this study, I aimed to investigate how firms reposition their IPR mechanisms with intentions to align these assets

[9] In Figures 1 and 2, the minimum value for OSS portfolio is below zero because the representative values were obtained on the basis of the mean-centered values of the explanatory variables that I used to compute the interaction terms.

[10] Gross profit margin, also known as profit margin, is a commonly used accounting measure of performance that can be calculated by the following simple formula: Gross profit/Net sales.

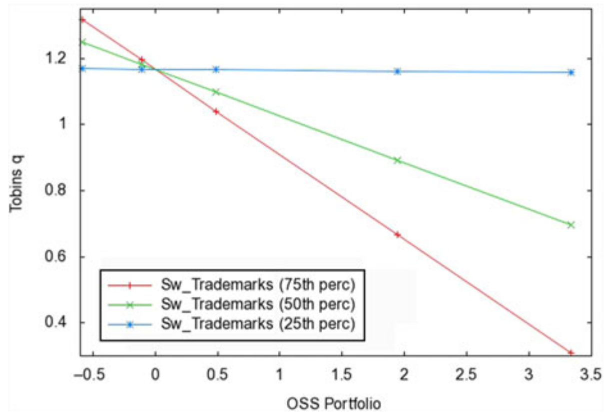

Figure 1. Oss portfolio and Tobin's *q* at different levels of software trademark stocks

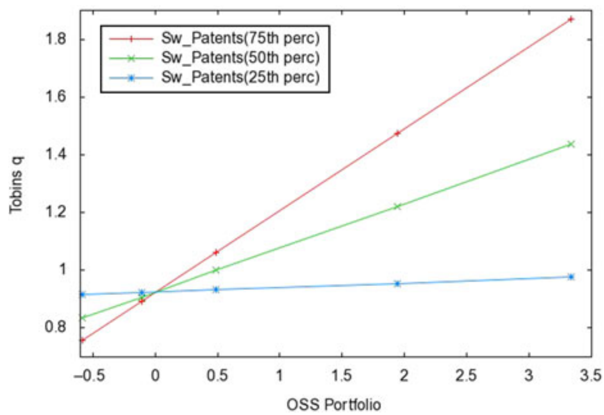

Figure 2. Oss portfolio and Tobin's *q* at different levels of software patent stocks

better with their business model. Because the focus of the study is on OSS commercialization, which is a long-term business model-building activity of a firm, use of Tobin's *q* as a forward-looking measure of performance is well-suited to the aims of this study. Moreover, Tobin's *q* is risk adjusted and less prone to manipulation than accounting measures of performance (Montgomery and Wernerfelt 1988).

5. Discussion and Conclusion

This study has two key findings. First, there is no direct positive effect of OSS portfolio on firm value. This suggests that the profitability of OSS commercialization is not as straightforward as that of proprietary software commercialization. In particular, appropriating returns from OSS commercialization cannot be achieved without complementary products/ services in proprietary segments and the corresponding IPR endowments because protecting the *commons* is the main challenge. Second, I assess the importance of firms'

IPR protection mechanisms and, specifically, software patents and software trademarks. OSS is a special case that challenges classical appropriation mechanisms because of its open nature. However, I observe indirect positive/negative effects of software patents/software trademarks on the relationship between OSS commercialization and firm value. Specifically, I find that large software patent stocks help firms perform better when they commercialize OSS products. In contrast, large software trademarks have a negative effect on the relationship between OSS product portfolio and firm value.

The findings contribute to the current debate on commercialization of OSS, mainly by establishing the intermediary effect of firms' IPR holdings on the relationship between OSS commercialization and financial performance. Although studies have investigated the link between OSS engagement and performance (Stam 2009; Alexy and George 2013), the moderating role of IPR mechanisms needed to be investigated because they are crucial firm resources in appropriating returns. By extending the work of Fosfuri, Giarratana, and Luzzi (2008), which emphasizes the role of IPR mechanisms in firms' decision to engage in OSS commercialization, this study sheds light on how much these mechanisms matter for extracting financial value from OSS commercialization. Moreover, the study empirically shows that mismatching strategies can harm a firm's performance while the firm attempts to move to a new business model for better outcomes.

The transformation of OSS into a commercial strategy has obliged firms to reconsider their current business models. In doing so, managers must determine how much the fit of their IPR protection regimes with their business model matters for value capture. Successful commercialization techniques combined with appropriate choices of intellectual property endowments can help firms capture the value created through open innovation models. Firms that aim to use advantageous attributes of OSS to create and appropriate value must overcome the challenge of adjusting their respective resources in a way that is consistent with their current business model. Considering the findings of this study, one might expect a firm that commercializes OSS to register for fewer software trademarks and to invest heavily in software patenting. My findings, which favor software patenting rather than trademark filing in an open source setting, further indicate that the adequacy of a firm's appropriation mechanism for its business model determines how much value it can capture. In this case, OSS commercialization may harm firms if they make wrong choices in their appropriation mechanisms.

Insufficient information about the development processes for commercial OSS products and the licensing schemes under which they are released prevented me from undertaking a deeper analysis on the impact of OSS commercialization on firm value. It would have been helpful to know whether each product introduced to the market was a direct complement of a formerly introduced product of the same company (e.g., plug-in, extension). Another possibility would be examining the effect of copyrights, as a potential isolating mechanism, on the relationship between new OSS products and firm performance. The management model of the community and different firm participation strategies may also help explain the success/failure of the outcome OSS products to be commercialized. The insights put forward in this study should encourage researchers to investigate the profitability of OSS commercialization. I leave further investigation on potential explanatory variables, such as underlying licensing schemes, development processes and governing methods, which may explain the heterogeneities in returns generated by OSS commercialization, for future research.

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No potential conflict of interest was reported by the authors.

References

Alexy, O., and G. George. 2013. “Category Divergence, Straddling, and Currency: Open Innovation and the Legitimation of Illegitimate Categories.” *Journal of Management Studies* 50 (2): 173–203. doi:10.1111/joms.12000.

Alexy, O., and M. Reitzig. 2013. “Private-Collective Innovation, Competition, and Firms’ Counterintuitive Appropriation Strategies.” *Research Policy* 42 (4): 895–913. doi:10.1016/j.respol.2013.01.004.

Allison, J. R., and M. A. Lemley. 2000. “Who’s Patenting What? An Empirical Exploration of Patent Prosecution.” *Vanderbilt Law Review* 58: 2099–2148.

Allison, J. R., and E. H. Tiller. 2003. “Internet Business Method Patents.” In *Patents in the Knowledge-Based Economy*, edited by W. M. Cohen and S. A. Merrill, 259–284. Washington, DC: National Academies Press.

Barney, J. B. 1986. “Strategic Factor Markets: Expectations, Luck, and Business Strategy.” *Management Science* 32 (10): 1231–1241. doi:10.1287/mnsc.32.10.1231.

Behlendorf, B. 1999. “Open Source as a Business Strategy.” In *Open-Sources: Voices from the Open Source Revolution*, edited by C. DiBona, S. Ockman, and M. Stone, 149–170. Sebastopol, CA: O’Reilly.

Bessen, J., and R. M. Hunt. 2007. “An Empirical Look at Software Patents.” *Journal of Economics & Management Strategy* 16 (1): 157–189. doi:10.1111/j.1530-9134.2007.00136.x.

Bharadwaj, A. S., S. G. Bharadwaj, and B. R. Konsynski. 1999. “Information Technology Effects on Firm Performance as Measured by Tobin’s *q*.” *Management Science* 45 (7): 1008–1024. doi:10.1287/mnsc.45.7.1008.

Blind, K., K. Cremers, and E. Mueller. 2009. “The Influence of Strategic Patenting on Companies’ Patent Portfolios.” *Research Policy* 38 (2): 428–436. doi:10.1016/j.respol.2008.12.003.

Bonaccorsi, A., S. Giannangeli, and C. Rossi. 2006. “Entry Strategies Under Competing Standards: Hybrid Business Models in the Open Source Software Industry.” *Management Science* 52 (7): 1085–1098. doi:10.1287/mnsc.1060.0547.

Bonaccorsi, A., and C. Rossi. 2003. “Why Open Source Software Can Succeed.” *Research Policy* 32 (7): 1243–1258. doi:10.1016/S0048-7333(03)00051-9.

Bureau of Industry Economics. 1994. *The Economics of Patents*. Occasional Paper 18 Canberra: Bureau of Industry Economics.

Chesbrough, H. W. 2003. *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Boston, MA: Harvard Business School Press.

Chung, K. H., and S. W. Pruitt. 1994. “A Simple Approximation of Tobin’s *q*.” *Financial Management* 23 (3): 70–74. doi:10.2307/3665623.

Dahlander, L. 2005. “Appropriation and Appropriability in Open Source Software.” *International Journal of Innovation Management* 9 (3): 259–285. doi:10.1142/S1363919605001265.

Dahlander, L., and M. G. Magnusson. 2005. “Relationships Between Open Source Software Companies and Communities: Observations from Nordic Firms.” *Research Policy* 34 (4): 481–493. doi:10.1016/j.respol.2005.02.003.

Dougherty, D., and T. Heller. 1994. “The Illegitimacy of Successful Product Innovation in Established Firms.” *Organization Science* 5 (2): 200–218. doi:10.1287/orsc.5.2.200.

Feller, J., and B. Fitzgerald. 2002. *Understanding Open Source Software Development*. Boston, MA: Addison-Wesley.

Fitzgerald, B. 2006. “The Transformation of Open Source Software.” *MIS Quarterly* 30 (3): 587–598.

Fosfuri, A., M. S. Giarratana, and A. Luzzi. 2008. “The Penguin Has Entered the Building: The Commercialization of Open Source Software Products.” *Organization Science* 19 (2): 292–305. doi:10.1287/orsc.1070.0321.

Gambardella, A., P. Giuri, and A. Luzzi. 2007. “The Market for Patents in Europe.” *Research Policy* 36 (8): 1163–1183. doi:10.1016/j.respol.2007.07.006.

Gans, J. S., and S. Stern. 2010. “Is There a Market for Ideas?” *Industrial and Corporate Change* 19 (3): 805–837. doi:10.1093/icc/dtq023.

Goldman, R., and R. Gabriel. 2005. *Open Source as Business Strategy: Innovation Happens Elsewhere*. San Francisco, CA: Morgan Kaufmann.

Graham, S. J., and D. C. Mowery. 2003. “Intellectual Property Protection in the US Software Industry.” In *Patents in the Knowledge-Based Economy*, edited by W. M. Cohen and S. A. Merrill, 231. Washington, DC: National Academies Press, National Research Council.

Hall, R. 1992. “The Strategic Analysis of Intangible Resources.” *Strategic Management Journal* 13 (2): 135–144. doi:10.1002/smj.4250130205.

Hall, B. H., and M. MacGarvie. 2010. “The Private Value of Software Patents.” *Research Policy* 39 (7): 994–1009. doi:10.1016/j.respol.2010.04.007.

Hall, B. H., and R. H. Ziedonis. 2001. “The Patent Paradox Revisited: An Empirical Study of Patenting in the U.S. Semiconductor Industry, 1979–1995.” *The RAND Journal of Economics* 32 (1): 101–128. doi:10.2307/2696400.

Hardy, Q. 2013. “Facebook’s Other Big Disruption.” *The New York Times*.

Hausman, J. A. 1978. “Specification Tests in Econometrics.” *Econometrica* 46 (6): 1251–1271. doi:10.2307/1913827.

Hecker, F. 1999. “Setting Up Shop: The Business of Open-Source Software.” *IEEE Software* 16 (1): 45–51. doi:10.1109/52.744568.

Henkel, J. 2006. “Selective Revealing in Open Innovation Processes: The Case of Embedded Linux.” *Research Policy* 35 (7): 953–969. doi:10.1016/j.respol.2006.04.010.

von Hippel, E., and G. von Krogh. 2003. “Open Source Software and the Private-Collective Innovation Model: Issues for Organization Science.” *Organization Science* 14 (2): 209–223. doi:10.1287/orsc.14.2.209.14992.

Lakhani, K. R., and E. von Hippel. 2003. “How Open Source Software Works: Free User-to-User Assistance.” *Research Policy* 32 (6): 923–943. doi:10.1016/S0048-7333(02)00095-1.

Lakhani, K. R., and R. G. Wolf. 2005. “Why Hackers Do What They Do: Understanding Motivation and Effort in Free/Open Source Software Projects.” In *Perspectives on Free and Open Source Software*, edited by J. Feller, B. Fitzgerald, S. A. Hissam, and K. R. Lakhani, 3–22. Cambridge, MA: MIT Press.

Lerner, J., and J. Tirole. 2002. “Some Simple Economics of Open Source.” *The Journal of Industrial Economics* 50 (2): 197–234. doi:10.1111/1467-6451.00174.

Lerner, J., and J. Tirole. 2005. “The Scope of Open Source Licensing.” *Journal of Law, Economics, and Organization* 21 (1): 20–56. doi:10.1093/jleo/ewi002.

Levin, R. C., A. K. Klevorick, R. R. Nelson, S. G. Winter, R. Gilbert, and Z. Griliches. 1987. “Appropriating the Returns from Industrial Research and Development.” *Brookings Papers on Economic Activity* 1987 (3): 783–831. doi:10.2307/2534454.

Lindenberg, E. B., and S. A. Ross. 1981. “Tobin’s *q* Ratio and Industrial Organization.” *The Journal of Business* 54 (1): 1–32. doi:10.1086/296120.

Mann, R. J. 2006. “Commercializing Open Source Software: Do Property Rights Still Matter?” *Harvard Journal of Law & Technology* 20: 1–46.

Mendonça, S., T. S. Pereira, and M. M. Godinho. 2004. “Trademarks as an Indicator of Innovation and Industrial Change.” *Research Policy* 33 (9): 1385–1404.

Montgomery, C. A., and B. Wernerfelt. 1988. “Diversification, Ricardian Rents, and Tobin’s *q*.” *The RAND Journal of Economics* 19 (4): 623–632. doi:10.2307/2555461.

O’Mahony, S. 2003. “Guarding the Commons: How Community Managed Software Projects Protect Their Work.” *Research Policy* 32 (7): 1179–1198. doi:10.1016/S0048-7333(03)00048-9.

O’Mahony, S., and F. Ferraro. 2007. “The Emergence of Governance in an Open Source Community.” *Academy of Management Journal* 50 (5): 1079–1106. doi:10.5465/AMJ.2007.27169153.

Raymond, E. S. 1999. *The Cathedral and the Bazaar: Musings on Linux and Open Source by an Accidental Revolutionary*. Sebastopol, CA: O’Reilly & Associates.

Riggs, W., and E. von Hippel. 1994. “Incentives to Innovate and the Sources of Innovation: The Case of Scientific Instruments.” *Research Policy* 23 (4): 459–469. doi:10.1016/0048-7333(94)90008-6.

Rumelt, R. P. 1984. "Towards a Strategic Theory of the Firm." In *Resources, Firms, and Strategies: A Reader in the Resource-Based Perspective*, edited by R. B. Lamb, 131–145. Englewood Cliffs, NJ: Prentice-Hall.

Schmidt, K., and M. Schnitzer. 2003. "Public Subsidies for Open Source? Some Economic Policy Issues of the Software Market." *Harvard Journal of Law & Technology* 16 (2): 474–502.

Shah, S. 2006. "Motivation, Governance, and the Viability of Hybrid Forms in Open Source Software Development." *Management Science* 52 (7): 1000–1014. doi:10.1287/mnsc.1060.0553.

Shapiro, C. 2001. "Navigating the Patent Thicket: Cross Licenses, Patent Pools, and Standard Setting." In *Innovation Policy and the Economy*, edited by A. B. Jaffe, J. Lerner, and S. Stern, 119–150. Cambridge, MA: MIT Press.

Stam, W. 2009. "When Does Community Participation Enhance the Performance of Open Source Software Companies?" *Research Policy* 38 (8): 1288–1299. doi:10.1016/j.respol.2009.06.004.

Teece, D. J. 1986. "Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy." *Research Policy* 15 (6): 285–305. doi:10.1016/0048-7333(86)90027-2.

Teece, D. J. 1998. "Capturing Value from Knowledge Assets: The New Economy, Markets for Know-How, and Intangible Assets." *California Management Review* 40 (3): 55–79. doi:10.2307/41165943.

West, J. 2003. "How Open Is Open Enough?." *Research Policy* 32 (7): 1259–1285. doi:10.1016/S0048-7333(03)00052-0.

West, J., and S. Gallagher. 2006. "Challenges of Open Innovation: The Paradox of Firm Investment in Open-Source Software." *R and D Management* 36 (3): 319–331. doi:10.1111/j.1467-9310.2006.00436.x.