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Organizational adoption of open source software

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ABSTRACT

Organizations and individuals can use open source software (OSS) for free, they can study its internal workings, and they can even fix it or modify it to make it suit their particular needs. These attributes make OSS an enticing technological choice for a company. Unfortunately, because most enterprises view technology as a proprietary differentiating element of their operation, little is known about the extent of OSS adoption in industry and the key drivers behind adoption decisions. In this article we examine factors and behaviors associated with the adoption of OSS and provide empirical findings through data gathered from the US Fortune-1000 companies. The data come from each company's web browsing and serving activities, gathered by sifting through more than 278 million web server log records and analyzing the results of thousands of network probes. We show that the adoption of OSS in large US companies is significant and is increasing over time through a low-churn transition, advancing from applications to platforms. Its adoption is a pragmatic decision influenced by network effects. It is likelier in larger organizations and those with many less productive employees, and is associated with IT and knowledge-intensive work and operating efficiencies.

1. Introduction

Thousands of volunteers and numerous companies develop, distribute, and license software in a way that allows others to freely use it, study it, modify it, and redistribute it. What are the prospects of the organizational adoption of this so-called open source software (OSS) and why should we care?

In this paper, through a novel application of web server log scanning and host fingerprinting techniques, we gather evidence of OSS adoption among the US Fortune-1000 companies, and use it to examine factors associated with OSS adoption. Our observations are statistically significant and span a wide sample of companies. However, although each research question we test is backed by existing theories, we freely admit that our study as a whole is data-driven rather than grounded on a single cohesive theoretical framework. Our main contributions are: (a) findings that theoretical frameworks of organizational OSS adoption could build upon and should be able to explain, and (b) the description and demonstration of powerful internet-based methods for collecting data about an organization's IT operations.

A commonly accepted OSS definition (Coar, 2006) specifies that complying software must be licensed for free redistribution (at no cost or for profit), must provide access to its source code, should allow the creation of derived works provided they respect the creation of the original author, and should not restrict the use of the software with reference to specific persons, groups, fields of endeavor, products, technologies, or other software. Well-known examples of open source software include the Linux operating system kernel, the Mozilla Firefox web browser, the OpenOffice.org office application suite, the MySQL relational database system, and the PHP programming language. Many OSS products offer plausible alternatives to the corresponding proprietary products, while some, like the the Apache web server, the Sendmail mail server, and the BIND domain name system server, are market leaders in their categories (Netcraft Ltd., 2009; E-Soft Inc., 2007; Simpson and Bekman, 2007; Kerner, 2007).

With its roots in the academic world OSS was initially viewed with suspicion by some companies. As a representative example, Microsoft openly attacked it citing problems related to version incompatibilities, intellectual property risks (especially in the context of copyleft licenses), lack of a credible business model, and an inability to fund innovation (Mundie, 2001; The Economist, 2001). However, other IT companies have embraced it for operational or strategic reasons. One example of operational use involves Google's thousands of servers, which work on a modified version of Linux, thus benefiting the company through the system's low cost and the ability to modify it to suit its needs (Weber, 2005, p. 6). As another example consider Apple, which has used OSS code from the Mach and FreeBSD operating systems to leapfrog in the development of its widely acclaimed Mac OS X operating system (West, 2003). On the

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strategic front, IBM has built a large community of developers and potential clients around the open source Eclipse integrated software development environment (Gamma and Beck, 2004), while Sun – before becoming part of Oracle – created a huge (though commercially underutilized) mindshare among programmers and system administrators with the open-sourcing of its Java platform and Solaris operating system (Goldman and Gabriel, 2005).

Proponents of open source software advance various arguments regarding the benefits of its adoption (West and Dedrick, 2001; Wheeler, 2007; Ven and Verelst, 2006) – see Section 2.1. There is also considerable anecdotal evidence on the use of OSS in non IT companies (see references in Section 2.3). However, theories and arguments on the adoption of OSS are seldom substantiated by empirical data, and the available data are patchy, difficult to replicate and quantify, and unsuitable for deriving generally useful theories and prescriptive results. To address these problems we analyze factors associated with the adoption of OSS (Section 3) and validate them empirically through the analysis of data collected for the US Fortune-1000 companies (Section 5). The data come from each company's web browsing and serving activities, gathered by sifting through more than 278 million web server log records and analyzing the results of thousands of network probes (Section 4).

There are several reasons motivating our study. First, patterns of OSS adoption in the Fortune-1000 companies reveal best practices, challenges, and opportunities that may be applicable to other organizations. Given the role of knowledge barriers in technology diffusion (Attewell, 1992), our findings outline the role of an ecosystem that can lower them. In addition, the software industry forms a vital and important part of the US economy (Rubin et al., 2002). The emergence of OSS is likely to form a disruptive change. Therefore, companies developing proprietary software can study OSS adoption patterns to best determine how to adjust their business models. Moreover, the agile end-user and volunteer-driven practices used for developing open source software differ markedly from the more rigid processes often followed in the development of proprietary software. Thus, the commercial adoption of products developed under the OSS model can be a precursor to wider changes on how many other products are developed and marketed (von Hippel, 1998, 2001). Finally, for-profit and volunteer OSS development organizations can study the way their products are adopted in order to optimize their offerings and their dissemination strategies.

2. Related work

Theories and empirical data related to this article fall roughly into four fields: organizational adoption of IT innovation, research on the adoption of OSS by organizations, studies of OSS adoption at an aggregate level, and reports on specific cases of OSS use. We examine work related to this paper's specific research questions and in particular the organizational adoption of IT innovation in Section 3.

2.1. OSS adoption by organizations

For the choice of software that fits best an organization's needs Wang and Wang (2001) proposed criteria for a product-oriented evaluation framework. They used this framework to compare open source systems, arguing that most of the criteria one must consider when choosing an OSS are common with those of proprietary software selection.

Searching why and how enterprises adopt open source Dedrick and West (2003), based on a series of interviews with MIS managers, developed a grounded theory of open source platform adoption. They classified the inherent factors they found into five categories: the willingness to take risks on a new and unproven technology, the need for organizational slack to evaluate the new technology and to self-support unsponsored technologies, the low cost of open source software, the inherent trialability of "free" software distributed on the internet, and the availability of external sources of support and expertise. An important contribution of this study is the suggestion for researchers to study the innovation adoption decision separately from the issues associated with switching between standards.

This advice was coincidentally followed by Glynn et al. (2005) who investigated a case of large-scale OSS adoption in a specific organization. Significant factors proved to be: the possibility of collaborating in a reciprocal fashion with the OSS community, the awareness of other organizations that were adopting OSS, cost, the availability of OSS-literate personnel, and the ability to modify and access the source code.

Research around benefits and significant factors driving OSS adoption, has led to the conclusion that the most important reason of choosing open source is purchasing cost and the total cost of ownership (Forrester, 2008). Although other benefits like stability and performance (Berlecon Research, 2002), flexibility and control (The Dravis Group, 2003), external support (Ven and Verelst, 2006) and security (Walli et al., 2005) are also stressed in the advantages listed by open source adopters, it seems that total cost of ownership and lower acquisition cost are the most significant ones.

On the other hand, there are also many factors that operate as barriers toward the organizational adoption of oss. Among them the most important ones seem to be knowledge barriers, integration with legacy applications, uncertainties introduced by forking, sunk costs, and technological immaturity (Nagy et al., 2010).

2.2. Aggregate studies of OSS adoption

Numerous studies examine OSS adoption across whole regions, industries, or application domains. More detailed presentations of such work can be found in a survey conducted by UNU-MERIT (2006), Wheeler's (2007) article on the reasons of choosing OSS, and recent work on the dynamics of the OSS community (Deshpande and Riehle, 2008).

In brief, studies agree that web and database servers are the most common types of OSS used. According to Unisphere Research (2006) 71% of Linux users chose it to host their web servers and 65% for their databases. Examining the adoption of web servers, evidence suggests that open source is the most popular choice, mainly because of the Apache web server with its adoption showing a rising trend during the last 15 years (Netcraft Ltd., 2009; E-Soft Inc., 2009). Examining the use of open source operating systems, studies have reported that OSS adoption on servers is markedly higher than on PCs and workstations. Specifically, Netcraft Ltd (2001) found that 45% of operating systems used by computers running public internet web sites was open source, just 4.5 percentage points below Microsoft's share. Gradually the adoption of OSS is moving beyond the server market extending along the entire software and application stack. Forrester (2008), in a study of companies using OSS for experimental projects or prototyping on a group level, found that 62% used OSS desktop applications and 71% OSS programming languages. Finally, on the sectoral distribution of OSS adoption two studies report that firms in the telecommunications sector are the ones most likely to adopt OSS (Walli et al., 2005; IDC, 2005), while several surveys indicate the importance of a firm's size in OSS adoption (Walli et al., 2005; Unisphere Research, 2006). These last two findings are examined and discussed later in our paper.

2.3. Specific cases of OSS adoption

We searched existing publications looking for specific cases of OSS adoption categorizing them according to the applications used,

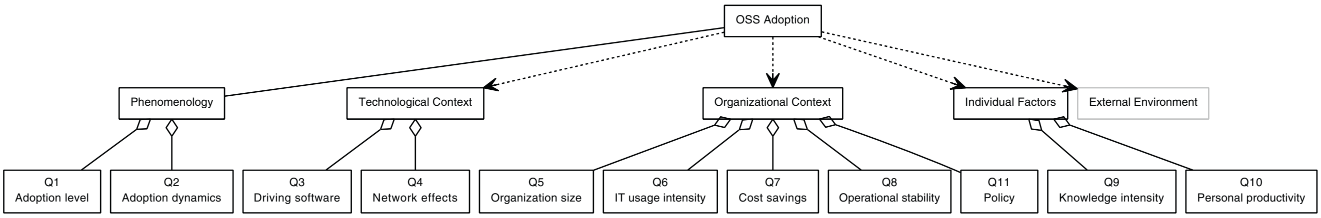

Fig. 1. The research questions mapped on the theoretical framework by Glynn et al. (2005).

the organization in which they were used, and the reasons cited for choosing OSS.[1] We found relatively few studies and even fewer containing enough details in all three areas. It is therefore not prudent to derive reliable conclusions from the sum of these studies.

From the studies we examined, 17 organizations used OSS for providing back-office functionality, two for sales support, eight in their R&D activities, and more than 30 for unspecified purposes. Reasons cited for choosing OSS include *lower cost* (Voth, 2003; Proctor et al., 2003; Searls, 2004; Fitzgerald and Kenny, 2004; Rossi et al., 2005; Matthews et al., 2008), *lower hardware cost* (IDC, 2001a, Geiszler et al., 2004; Woods and Guliani, 2005, p. 85), *software features* (IDC, 2001b; Yang and Jiang, 2007; Matthews et al., 2008), *lower total cost of ownership* (Gupta et al., 2008), *quick deployment* (Searls, 2003), *portability across platforms* (Voth, 2003), *avoidance of formal procurement and commercial license management* (Voth, 2003), and *customizability* (Proctor et al., 2003).

3. Theory and research questions

Before posing our research questions we must set straight our terminology: the meaning of OSS adoption and its relationship to its actual use. A thorny issue in the diffusion of innovation studies are adoption's so-called *assimilation gaps*, which in the case of information systems are observed as the difference between an information system's acquisition and its productive deployment (Fichman and Kemerer, 1999). Gallivan (2001) made a similar observation by distinguishing between *primary adoption* where management decides that a particular information system is required cover a perceived need, and *secondary adoption* where the organization integrates the information system at an operational level. This happens through a process of assimilation, which advances through the stages of initiation, adoption, adaptation, acceptance, routinization, and infusion.

In the case of OSS, acquisition is a lightweight process, which may simply consist of downloading the software, perhaps after clearing licensing issues with the organization's internal-control department. Furthermore, the data we collected provide evidence of actual use in the case of the web server and its underlying operating system, while the policies of the organizations we study make it unlikely that observations of OSS use on the client side are isolated occurrences (see Section 4). Therefore, in our study we employ the term adoption to denote small to full scale deployment and actual use.

There are many questions that an empirical study on the adoption of OSS can help answer. We start by looking at the industry-wide dynamics of OSS adoption, continue by focusing on individual companies, and finish by examining some interesting people-related aspects. The research questions of our study neatly match the three of the four macro-factors identified by Glynn et al. (2005); see Fig. 1. Two questions, Q1 and Q2, are of a phenomenological nature, examining the current status and outlook of OSS adoption. From the research framework we use as a basis, we investigate some of the possible *technological* factors through questions Q3, Q4, *organizational* factors through Q5, Q6, Q7, Q8, Q11, and *individual* factors through Q9, Q10. Although Q4 helps us investigate inter-environmental factors, unfortunately, we lack data to investigate factors of the external environment.

One might be tempted to map the five critical factors proposed for determining the use of agile or plan-driver development methods to those applicable for choosing to use OSS. There are certainly some parallels between the factors and our questions: size (Q5), criticality (Q9), dynamism (Q8), personnel (Q10), culture (Q11). However, given that there is no reason to think that the choice of OSS somehow relates to agility, we chose not to pursue this angle.

There are also other studies on OSS and its adoption. A number of them propose reasons for a company to adopt software development techniques used by OSS projects (Boehm and Turner, 2004) or to participate in the development of an OSS project (Feller and Fitzgerald, 2001). The reasons proposed are however not directly applicable to our research questions. Moreover, although the adoption of information systems and software applications has been examined in depth – Jeyaraj et al. (2006) provide a comprehensive review of several proposed theories – we believe that the particular characteristics of OSS and the type of data we collected benefit from using the more specialized framework presented in Fig. 1.

Research Question 1. What is the level of OSS adoption in large US companies?

The quantitative OSS adoption indicators we presented in Section 2.2 show that OSS has long passed the market introduction stage but has not yet reached the maturity stage. In fact, an analytical study has proved that by following appropriate strategic decisions open source and proprietary software can coexist in a duopoly (Casadesus-Masanell and Ghemawat, 2006). We therefore believe that OSS is a mainstream product alternative currently in the growth phase.

Research Question 2. What are the dynamics of OSS adoption by individual companies?

An important question associated with the dynamics of OSS adoption is the behavior of individual organizations across time. Are organizations dipping their feet in the water only to retreat from OSS after receiving a cold shower, or are they satisfied by its benefits and increase the areas in which they adopt it? Marketing practitioners use the term *churn rate* to describe the number of customers entering and leaving their pool. Similar measures are customer turnover, defection, and attrition rates. In our case a high churn rate – organizations adopting OSS in one year only to go back to proprietary software in a next one – would indicate problems in the technology's adoption, even in the face of an increasing overall adoption rate. In contrast, an increasing scope of OSS products used might indicate that the organization is happy with OSS and seeks to expand its perceived benefits to other areas.

The two main factors that might impede a company's replacement of proprietary systems with OSS ones of equivalent functionality are switching costs (von Weizsacker, 1984; Brynjolfsson, 1993; Bessen, 2002) and customer loyalty (Dick and

[1] In our search we ignored grey-literature sources, such as web sites, pamphlets, and trade press articles.

Basu, 1994). Once these considerable obstacles are overcome we would expect a stable flow of transitions prompted by the various benefits of OSS outlined in Sections 2.1 and 2.3 and also presented in other studies (West and Dedrick, 2001; Wheeler, 2007).

Research Question 3. In what order is OSS adopted within a company?

Do companies adopting OSS work bottom-up from the operating system (which many consider a commodity) and progress to the more business-critical applications, or do they avoid the disruption of an operating system switch and instead test the waters in the application space? The main determinants here are the decomposition of software into applications and infrastructure (Messerschmitt and Szyperski, 2004, pp. 200–204), the advantages enjoyed by platform leaders (Cusumano, 2004, pp. 74–77), and the importance of network effects (Shapiro and Varian, 1999).

One argument is that pragmatic users want particular results from their IT infrastructure (for instance, obtaining or serving web pages). These can often be provided by an OSS application, and this scenario can be easily tested by deploying such applications on the existing operating system. Once an OSS application is installed and proves its value, the underlying operating system can also be switched to an open source one, because the proprietary application that required a corresponding operating system has been removed. This mode of adoption minimizes the drag of earlier technology on IT adoption (Fichman and Kemerer, 1993), and at the same time builds on the learning effects that may arise from the earlier use of a technology (Stoneman, 1981).

Other factors affecting the order of adoption include the risk associated with particular changes (critical real-time customer-serving systems, versus less-critical batch-oriented back-office operations), as well as the levels of trust the company places on various parts of an OSS ecosystem.

Research Question 4. Is the selection of proprietary software or OSS subject to network effects?

In the preceding research question 3 we posit a particular technology-based adoption scenario. However, there may also be the case that that there are concrete network-specific advantages in using applications of a particular type (open source or proprietary). Several studies have examined the important effect of network externalities in a technology's adoption using both theoretical methods (Katz and Shapiro, 1986, 1994; Economides and Katsamakas, 2006) and empirical findings (Saloner and Shepard, 1995; Majumdar and Venkataraman, 1998; Gowrisankaran and Stavins, 2004).

Intra-organizational network effects (i.e. component selection interactions *within* a company's boundaries) associated with the adoption of OSS can be direct or indirect. The direct effects are associated with the prevalence of a particular product within the organization where it enjoys advantages over a competing product in the areas of IT support, software provision (Church and Gandal, 1992), and training. For instance, if all a company's PCs run Microsoft Windows, its IT administrators may find it easier to run the same system also on their servers. The indirect or two-sided network effects (Parker and Van Alstyne, 2005) are associated with the co-existence of different but complementary products, such as the operating system and the application running on it, or the web server and the corresponding browser. In this case, products of the same kind benefit through their superior interoperability, through the availability of bundled licenses and support contracts, and through the organization's contacts with (the typically segregated) support communities. This has been empirically validated for the case of web servers and browsers (Gallaugher and Wang, 2002). As a concrete example, if a company writes its software using Microsoft's .NET development tools this will run reliably only the company's Windows systems.

Based on the above description, we consider OSS and proprietary applications as two disjoined networks with interoperability challenges. Specifically, we examine whether a particular organization will try to use either OSS applications or proprietary ones, rather than mix the two kinds freely together.

Research Question 5. How is an organization's size affecting the adoption of OSS?

Let us now switch our view from the dynamics of OSS adoption to the organizations adopting OSS. The relationship between a company's size and IT adoption can be viewed either from an IT management perspective (DeLone, 1981) or by looking at a company's organizational characteristics (Hannan and McDowell, 1984; Kelley and Helper, 1999). For the majority of organizations we have studied, the advantages of open source software are in most cases relatively small and tactical rather than strategic. However, they are compounded over the total number of installations and the size of a company's IT operations (Cohen and Levinthal, 1989), perhaps through economies of scale and scope. As an example, a company with thousands of employees running only standardized web-based applications could easily switch their PCs to run Linux and the Firefox web browser. Although such a move in a large organization will entail large switching costs, these are proportional to the organization's resources and therefore these large costs should not derail the choice of switching to new software.

Furthermore, studies have found that there is a positive relationship between organizational size, innovations, and their implementation (Damanpour, 1992), that large firms are more likely to adopt innovations before smaller ones (Davies, 1975, p. 118), that the establishment and firm sizes are positively related to ICT adoption (Bayo-Moriones and Lera-López, 2007), and that a firm's size also affects the availability of ICT-related skills (Morgan et al., 2006) and resources (Spanos et al., 2002), which are needed in a transition to OSS.

Research Question 6. How is IT usage intensity affecting OSS adoption?

Another element of scale efficiencies is not associated with a company's size, but with the intensity of IT usage within it. The theoretical underpinning is the same as that of the preceding question 5, but the driver is a higher density of IT installations. Compounding factors in this case are experience with IT technology (Venkatesh et al., 2003, pp. 433–435, 447) and technical know-how (Attewell, 1992). Thus, companies in fields with a high IT-usage intensity could be more likely to adopt OSS.

Research Question 7. Is OSS adoption associated with financial operating efficiencies?

Numerous studies have examined the influence on a company's performance of technology policy and adoption in general (Tornatzky and Klein, 1982; Zahra and Covin, 1993; Stoneman and Kwon, 1996) and IT in particular (Brynjolfsson, 1993; Brynjolfsson and Yang, 1996; Stiroh, 2002; Carr, 2003). On a first reading the results appear to be inconclusive. However, Hitt and Brynjolfsson in their classic 1996 paper used the theory of production and theories of competitive strategy to deduce that there is no inherent contradiction between increased productivity, increased consumer value, and unchanged business profitability.

In many cases the direct cost of purchasing OSS and keeping it up to date is zero or very low. If this cost is reflected in an overall lower total cost of ownership it could lead to increased profits. However, given that IT costs are typically a relatively low percentage of a company's total expenditures, it is more likely that the causal relationship will be the other way round. Namely, profitable well-run companies may be adopting OSS as an additional appropriate practice for lowering the cost and increasing the efficiency of their operations. This view is further strengthened by studies arguing that firms for which an innovation is most profitable will become early adopters (von Hippel, 1988; Attewell, 1992).

Research Question 8. How is an organization's stability affecting OSS adoption?

As posited by Nolan (1973) and others who have built on his work (King and Kraemer, 1984) the introduction of information technologies in an organization proceeds in distinct stages. Therefore, it is likely that the introduction of a new technology, like OSS, will face obstacles that will depend on the company's state of IT growth. Furthermore, the company's growth stage may also be a significant factor in the adoption of innovation. However, the theoretical arguments for this are conflicting. Younger, growing firms may benefit through their flexibility (Christensen and Rosenbloom, 1995) as well as through lower adjustment costs and modern capital stock, while older, stable companies may profit from their technological experience (Dunne, 1994). This conflict is also reflected in empirical studies: some report a positive relationship between an organization's age and its ability to innovate (Sorensen and Stuart, 2000) and others a negative one (Kimberly and Evanisko, 1981).

The introduction of OSS in an organization can be disruptive, and the evolution and maintenance of existing OSS installations trickier than comparable setups based on proprietary software. These problems can be less of an issue in a slower-growing, stable organization where change and therefore demands from IT staff are lower. Companies that are in a flux, as evidenced by increasing capital spending or sales, or high levels of debt, are more likely to minimize the risk of their IT operations (King et al., 1994; Fichman, 2000) by opting for proprietary solutions. In contrast, more stable companies that do not exhibit the previously mentioned characteristics may have established a culture for process improvements and have more appetite for IT risk and the ability to manage it effectively, and will therefore be more likely to adopt OSS.

Research Question 9. How is an organization's human capital occupation affecting OSS adoption?

A number of studies examine the characteristics of new technology adopters (Davis, 1989; Thompson et al., 1991; Venkatesh et al., 2003). The main causation factors include the judgment of one's ability to use technology – as modeled in the social cognitive theory of self-efficacy (Compeau and Higgins, 1995), the perceived relative advantage within the context of the innovation diffusion theory (Moore and Benbasat, 1991), and the role of experience (Venkatesh et al., 2003, pp. 433–435, 447). More specifically, Cohen and Levinthal (1989) found that human and knowledge capital are key determinants for a firm's ability to assess technological opportunities and adopt ICT, while Brynjolfsson and Hitt (2002) state that knowledge-intensive firms tend to be more eager IT adopters.

The case for the adoption of OSS can be further strengthened by hypothesizing that knowledge-intensive industries are more likely to realize a significant-enough return on investment on open source technologies that will warrant their adoption. In other industries the costs of switching to open source and supporting non-mainstream technologies may be difficult to justify, and, therefore, such industries will be less likely to adopt OSS.

Research Question 10. How is employee productivity affecting OSS adoption?

Open source software is often less polished than its proprietary alternatives; version proliferation and poor usability are two often-reported problems (Nichols and Twidale, 2003; Krishnamurthy, 2005; Viorres et al., 2007). Highly paid employees, like knowledge workers, may argue that the fit of the OSS (Thompson et al., 1991), the service quality it offers (DeLone and McLean, 2003), or the perceived behavioral control they have over it (Ajzen, 1991) is worse than that of its proprietary alternative. The key factors for resisting such change can be classified into people-oriented, system-oriented, and interaction theories (Jiang et al., 2000). As the cost of the software used by highly productive workers forms a small percentage of their total employment cost and the software's quality reflects a lot on their productivity, spending on industry-standard proprietary software may be a rational decision. Consequently, we could expect that the relative advantage of OSS viewed as an innovation (Moore and Benbasat, 1991; Rogers, 2003) will be marginal. As an example, traders with seven figure incomes are unlikely to skimp on the operating system running on their PCs.

Conversely, in Fortune 1000 companies with numerous but less productive employees adoption of cheaper though less polished OSS can offer significant cost advantages, and therefore management can easier mandate its use. For instance, we can easily imagine the cost savings associated with thousands of service desks running Linux and the Thunderbird mail client.

Research Question 11. Is the choice between OSS and proprietary software a matter of principle?

The choices between open source and proprietary software have been mainly analyzed in the context of business strategies (West, 2003) and the software industry (Economides and Katsamakas, 2006). Many open source adherents advocate the adoption of OSS on the basis of ideology (Gay, 2002), while opponents have cautioned against adoption by analyzing various risks (Mundie, 2001). We thus examine whether OSS ideology and risks carry real weight, or whether companies will choose between OSS and proprietary software platforms in a rational and pragmatic manner looking for their best interest (Aupperle et al., 1985; Clarkson, 1995), irrespective of the software's license.

4. Methodology

We conducted our study by examining web server logs and using network probes to look for evidence of OSS adoption among the US Fortune 1000 companies. Focusing on the Fortune 1000 companies benefited our study in a number of ways. First, their large size means that such companies are likely to adopt innovations before smaller ones Davies (1975, p. 118). In addition, the Fortune 1000 companies cover most sectors of the US economy, while their activity forms a large part of it. In fact, their revenues amount to about 41.5% of the total US corporate revenues for 2007 (US Census Bureau, 2009) and about half (49.6%) of the total profits (Wolfram, 2009). Large firms are also more likely to be export-oriented or multinational thereby increasing the study's applicability to a global audience. Furthermore, their large size increases the visibility of their operations, and makes them more likely to appear in our study's browser software radar. Finally, our choice meant that for all the companies we could readily obtain relatively reliable financial data, a sectoral categorization, and an address of an operating web site, and thereby also a probable domain-name address their employees use when accessing the web. Our study's US and large company focus confines somewhat its wider applicability, but the limitation is offset by the data's reliability and the sample's homogeneity.

To a large extent our method avoids the self-selection, recall, and pro-adopter biases (Rogers, 2003) that plague other studies (Jeyaraj et al., 2006). With a questionnaire-based study it would be probable that companies with antiquated IT strategies and systems would fail to respond; the same could also be true for companies whose IT management formed a tactical or strategic advantage. Both factors introduce a self-selection bias. Furthermore, self-reports are unreliable thus adding a recall bias. Finally, case studies often focus on adopters introducing a pro-adopter bias. By collecting hard objective data from a predefined sample we avoid these pitfalls, at the expense however, of loosing the ability to select all the questions we might want to answer.

4.1. Data collection and processing

We used a variety of techniques to obtain data about the software used on the companies' desktops and by their back-office operations. Due to the methods we used, we focused on three types of software in four distinct roles: the web browser (on the desktop), the web server (in the back-office), and the operating system on which the two are running (on the desktop and in the back-office).

To determine the desktop operating system and web browser software used by each company we examined web server logs. We collected about 55 GB of log files from three sources: our own servers (4.7 GB), servers of our personal contacts (11.6 GB), and files we located in the wild through Google queries (33.8 GB). In total the log files contained 278 million entries. Web servers record a log entry in a standardized format for every file they send to a web browser. For the purposes of our study the entry's important fields are the IP address, the date, and the client's software. As a first step we processed each entry to convert the (typically) numerical IP address, like 195.212.29.137 into a host name like blueice18n5.uk.ibm.com. We then went through all log entries looking for those where the last two parts of a client's hostname matched those of a Fortune 1000 company's web site address. For instance, the above host name would match IBM's web site address http://www.ibm.com. We identified 4.7 million records associated with Fortune 1000 companies. These requests included 16,705 unique machine signatures (an IP address, a browser, and an operating system triple). Finally, for each matching entry we examined the client software details to determine whether the web browser and the underlying operating system were proprietary or open source. As an example, the following client identification string

```
Mozilla/5.0 (Windows; U; Windows NT 5.1; en-US;
rv:1.9)
Gecko/2008052906 Firefox/3.0
```

corresponds to an open source browser (Firefox) running on a proprietary operating system (Microsoft Windows XP). We tabulated the results by company and year in a list specifying whether a company was found to use a proprietary or open source (or both) operating system or browser.

To determine the web server used by each company we retrieved the company's top web page using the *wget* tool, and logged the HTTP protocol headers. One of those headers contains an identification string of the web server, which we used to establish whether the company used a proprietary or an open source product.

To determine the operating system type we employed *nmap*, a network exploration and port scanning tool (Wolfgang, 2002). *Nmap* works by sending specific network packets to the host, and analyzing minute accidental differences in the responses that can be traced back to the responding computer's operating system. It then matches those results against a database of 1503 (for the version 4.76 we used) so-called operating system fingerprints. The match is probabilistic in nature and can often fail.

Obtaining historical data regarding the OSS adoption proved difficult. The method we used to obtain adoption evidence on the server side (the web server and its hosting operating system) provided us data only for the time we executed the probe. On the other hand, web server logs provided useful data for the client side (the web client and its hosting operating system) for a time period spanning from 2002 to 2009. We removed from the longitudinal study the data from 2009, because it formed an incomplete and therefore potentially biased sample. (Events that occurred rarely within a year would be underrepresented compared to the other, complete, years.) For a number of reasons, when looking for trends on OSS adoption we chose to look at the latest three years rather than the full six year period for which we had logs. First, the early logs came mainly from this paper's first author web site, which focuses on IT and OSS. This would introduce a bias due to the companies likely to access such material. Moreover, the available logs gave us required data only for 3.2% of the Fortune 1000 companies for the whole 2002–2008 period. Finally, data from the latest three years appear to give a considerably more representative sample of our population than data from the full six year period (see Table 1).

4.2. Threats to validity

There are several threats to the validity of this study; many are associated with the data we employed for identifying companies using open source operating systems and browsers.

The first problem concerns the small number of software systems we examine. A company may use hundreds of software systems for a variety of purposes, but we examine just four: the web browser, the web server, and their corresponding operating system hosts. We argue that these are ubiquitous and highly visible systems, from which we can derive generalizable lessons for desktop applications and system software. Nevertheless, lessons from these systems cannot apply to specialized vertical applications, and this remains a limitation of our study.

In addition, the time period we use for the research questions with a longitudinal component (Q1, Q2, and Q3) is very small (three years). This was a result of balancing data quality against time coverage, as explained in Section 4.1. For this reason we do not perform any longitudinal regression analysis, and base our findings on statistically significant results obtained for each year.

Table 1
Industry distribution in log data and among Fortune 1000 companies (%).

Industries by SIC	For each year 2002–2008	For each year 2006–2008	Any entry 2002–2009	Population
Agriculture, forestry and fishing	0.0	0.0	0.0	0.2
Construction	0.0	0.7	0.6	1.8
Finance, insurance and real estate	3.1	15.9	16.0	16.1
Manufacturing	59.4	40.3	38.5	37.7
Mining	3.1	2.2	2.9	3.6
Public administration	0.0	0.4	0.2	0.1
Retail trade	0.0	8.0	10.5	11.2
Services	21.9	15.9	13.9	11.3
Transportations, communications, electric gas and sanitary services	12.5	12.3	12.6	13.0
Wholesale trade	0.0	4.3	4.8	5.0

Table 2
Statistical results of *t*-test analysis.

OSS	Proxy	Mean		*t*-Test	*p*-Value
		Users	Non-users		
Any	Assets	45,132	21,392	2.7458	0.0061**
	Capital spending 5 year Growth rate	12.85	18.18	−2.8148	0.0050**
	Gross margin 5 year avg	36.52	32.00	2.9380	0.0034**
	Gross margin TTM[a]	34.57	29.42	3.3307	0.0009***
	Profits	851	569	1.6208	0.1054
	Positive profits	1,210	730	2.9193	0.0036**
	Revenue over employee TTM	667,525	1,563,088	−2.0478	0.0413*
	Revenues	14,270	9,191	3.0363	0.0025**
	Sales 5 year growth rate	11.53	15.58	−2.2555	0.0245*
Web browser	Revenues	16,932	9,544	3.3780	0.0008***
	Capital spending 5 year Growth rate	12.07	16.23	−2.0088	0.0462*
	Profits	993	491	2.2027	0.0281*
	Positive profits	1,455	660	4.2950	2.18×10^{-5}***
	Revenue over employee TTM	674,797	992,923	−1.9729	0.0509*
	Price to tangible book MRQ[b]	3.7790	2.2158	3.1306	0.0019**
Client OS	Revenues	24,839	12,395	3.3830	0.0010***
	Gross margin 5 year avg	40.95	3,515	2.2226	0.0277*
	Gross margin TTM	39.22	3,298	2.3548	0.0198*
	Profits	2,315	486	4.3463	2.79×10^{-5}***
	Positive profits	2,611	876	4.1299	0.0001***
	Revenue over employee TTM	540,980	819,519	−2.5600	0.0112*
Web server	Assets	45,856	19,258	2.5062	0.0127*
	Revenues	13,776	10,178	1.9698	0.0493*
	Gross margin 5 year avg	36.46	33.08	2.0094	0.0451*
	Revenue over employee TTM	621,814	1,326,272	−2.1751	0.0301*
	Sales TTM vs. TTM One year ago	5.0407	8.9279	−2.2109	0.0273*
Server OS	Capital spending 5 year growth rate	11.84	17.76	−2.5478	0.0115*
	Gross margin 5 year avg	40.02	33.52	2.3921	0.0180*
	Sales TTM vs. TTM One year ago	2.3631	10.9705	−3.2821	0.0011**

[a] Trailing twelve months.
[b] Most recent quarter.
* α=0.05.
** α=0.01.
*** α=0.001.

We determined the web browser and operating systems used in a company by looking at the log entries created during web browsing. However, the web server logs we collected form only a tiny fraction of a company's complete browsing activity. As detailed in Section 4.1, for all the Fortune-1000 companies we identified 4.7 million web page records; on average 4668 requests per company. These requests included 16,705 unique machine signatures giving us an average of 16.7 uniquely configured PCs per company. Therefore, our work shares the problems of any empirical study based on a small sample of field data.

Other, less important, possible sources of error include the parallel presence of OSS and proprietary applications, the provenance of the logs we examined, web requests performed by a company's visitors, the mapping of numerical IP addresses into host names, doctored HTTP headers, and limitations of the fingerprinting technique we employed.

A concern voiced by some of this work's reviewers is whether the use of a particular operating system or browser reflects a company's policy rather than choices of individual employees. For this reason studies of IT acceptance often distinguish between voluntary vs. mandatory contexts (Venkatesh et al., 2003) and stress the importance of employing a multilevel perspective. This criticism is justified, because we academics and researchers are blessed with virtually unlimited freedom regarding the choice, setup, and configuration of our computing infrastructure. However, the situation in industry is different. There, automated mass installations from a single stable configuration image, a severely constrained user ability to install new software, and rigidly enforced IT policies are the rule. In large listed companies externally imposed legal requirements and standards,[2] the provision of a standard operating environment, and the imposition of change management procedures align the software used by a company's employees with its policies.

5. Analysis and findings

In order to search relationships and differences between financial data and OSS we started by looking at the difference between the means of OSS users and non OSS users using the *t*-test method (Table 2). We then used the logistic regression model (Ross, 2004) based on the binomial distribution to find the specific relation between our measures and the type of software used (open source or proprietary) – see Table 3. We chose this model in order to handle the "evidence of OSS adoption" binary dependent variable. All the other analyses are commented in each research question and the corresponding results can be found in this paper's tables.

Research Question 1: Table 4 summarizes OSS adoption ratios for each one of the examined systems, as well as the number of observations that led to the corresponding results. We had at least one observation indicating the use of proprietary or open source

[2] Larsen et al. (2006) list 17 IT governance tools, among them the well-known Sarbanes-Oxley Act of 2002 (SOX) and Information Technology Infrastructure Library (ITIL).

Table 3
Statistical results of logistic regression analysis.

Dependent variable	Independent variable	Coefficient	Wald Z	p-Value
Open source software adoption	Assets	2.37×10^{-6}[a]	2.4732	0.0133*
	Capital spending 5 year growth rate	-9.10×10^{-3}	−2.6837	0.0073**
	Gross margin 5 year avg	1.03×10^{-2}	2.7788	0.0055**
	Gross margin TTM	1.07×10^{-2}	3.1186	0.0018**
	Profits	4.17×10^{-5}	1.5728	0.1158
	Positive profits	1.38×10^{-4}	2.8801	0.0040**
	Revenue/Empl TTM	-1.51×10^{-7}	−2.4287	0.0152*
	Revenues	1.09×10^{-5}	2.8715	0.0041**
	Sales 5 year growth rate	-9.97×10^{-3}	−2.1806	0.0292*
OSS web browser adoption	Revenues	1.81×10^{-5}	2.5934	0.0095**
	Capital spending 5 year growth rate	−0.0140	−2.1139	0.0345*
	Positive profits	0.0003	2.7849	0.0054**
	Revenue/Empl TTM	-2.32×10^{-7}	−2.3068	0.0211*
	Price to tangible book MRQ	0.1115	2.3704	0.0178*
OSS web client OS adoption	Revenues	1.42×10^{-5}	3.6523	0.0003***
	Profits	0.0003	4.7087	3.88×10^{-6}***
	Positive profits	0.0003	4.6175	2.49×10^{-6}***
	Gross margin 5 year avg	0.0112	2.1029	0.0355*
	Gross margin TTM	0.0119	2.2721	0.0231*
	Revenue/Empl TTM	-2.00×10^{-7}	−2.0097	0.0445*
	Price to tangible book MRQ	0.0515	2.0567	0.0397*
OSS web server adoption	Assets	2.25×10^{-6}	2.6807	0.0073**
	Gross margin 5 year avg	0.0079	2.0100	0.0444*
	Revenue/Empl TTM	-1.72×10^{-7}	−1.9599	0.0500*
	Sales TTM vs. TTM One year ago	−0.0070	−1.9668	0.0492*
OSS web server OS adoption	Capital spending 5 year growth rate	−0.0164	−2.3972	0.0165*
	Gross margin 5 year avg	0.0151	2.4482	0.0144*
	Gross margin TTM	0.0114	2.0096	0.0445*
	Sales TTM vs. TTM One year ago	−0.0188	−2.8322	0.0046**

For the significance of asterisks, see Table 2.

[a] The very small coefficient values are due to the very big difference between the values of the variables (0/1 for the dependent variable and many orders of magnitude higher values for the independent one). This also occurs in the other regression tests.

software for 964 out of the 1000 companies, and observations for all four software systems for 150 out of the 1000 companies.

Interpreting the observation numbers for the web server and its operating system is straightforward: an observation means that the company is using an open source product. The situation for the case of the web browser and its client operating system is more complex. In this case a single observation is one entry in the log files we collected. Mapping the number of observations to actual users or adopters is not easy, because (a) our sample is a small subset of a company's total web activity, and (b) the activity's origin is typically masked by the company's firewall and cannot be tracked back to an individual PC. However, we can extrapolate the meaning of our client observations by using known facts about Charter Communications, a Fortune 1000 internet service provider with a large number of users that are, by definition, active web users. According to the company's SEC filings, during our log sampling period Charter served 1.1 million customers at the end of 2002 and 3.1 million at the end of 2009, or about 2.1 million customers on average. During the same period we found in the logs we collected 5.4 million entries from charter.com addresses, giving us about 2.6 log entries per user. Extrapolating this ratio to other companies we see, for instance, that Boeing's 5.5 thousand open source browser log entries indicate a corresponding number of 2.1 thousand users.

As we can see in Table 4, in the case of the web browser and its client operating system there is a large difference (19–48%) between a single observation of client OSS use for a particular company (20.3% for the operating system and 72.5% for the browser) and the figure across all the observations (0.99% for the operating

Table 4
Evidence of open source adoption across companies and observations.

Software	Company observations	Adoption ratio and 95% confidence intervals (%) Low	Estimate	High
Client OS[a]	477	17.7	20.3	22.9
Web browser[b]	477	69.6	72.5	75.4
Server OS[c]	381	25.4	28.9	32.4
Web server[d]	905	31.8	32.8	33.8
Evidence for any of the above	964	55.3	55.9	56.5
Evidence for all of the above	150	73.3	79.3	85.3
	Request observations			
Client OS	4,668,399	0.98	0.99	1.00
Web browser	4,668,399	24.58	24.62	24.65

[a] Web log entry browser client identification. Example: Firefox/3.0.
[b] Web log entry client OS identification. Example: Linux i686 (x86_64).
[c] *nmap* operating system fingerprint. Example: Linux 2.6.X.
[d] HTTP protocol headers obtained with *wget*. Example: Apache/1.3.33.

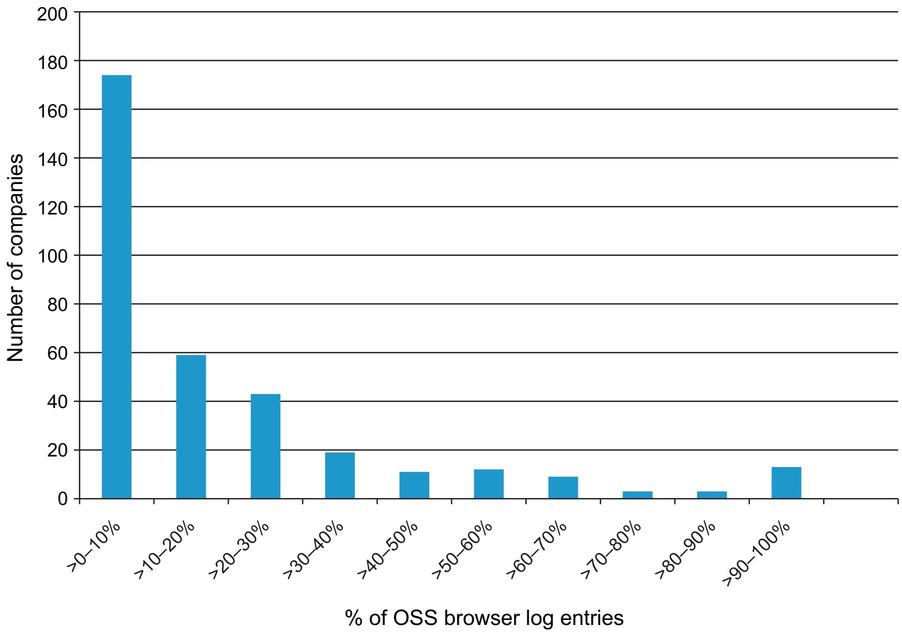

Fig. 2. Frequency distribution of OSS browser log data.

system and 24.62% for the browser). The frequency distribution of OSS client browser observations across the companies we found using an OSS browser is further elaborated in Fig. 2. It shows that from the 346 companies for which we found log entries corresponding to an OSS browser, at the one end 174 of them have entries corresponding to no more than 10% of all the company's log entries, while at the other end 13 have entries corresponding to more than 90% of all their log entries. This difference indicates that even companies that adopt OSS for some applications are loath to roll it out throughout their IT infrastructure, which in many cases remains wedded to proprietary systems. One might argue that we should base our study on the percentage of particular observations for each firm. However, we believe that data are not sufficiently representative to allow one to draw generalizable conclusions at this level of detail.

In Section 2.2 we showed that about half of the running web servers and a quarter of the web browsers are based on OSS; these are the most popular OSS applications. Therefore, the adoption figures we report for the four software applications are likely to be close to the upper bound for all possible software applications; the few companies that are not using OSS even in these popular niches are probably wed to proprietary software for a number of valid reasons, which are likely to also apply to other application areas. Such reasons include the availability of skills and sufficient funding to support the in-house maintenance of OSS applications, the provision of resources to promote ICT innovation, the projected returned on investment (explored in a number of our research questions), network effects (see Q4), specific functional requirements (see Q10), as well as the IT department's or the company's policy toward the use of OSS.

Regarding the level of OSS adoption and its change over time, we were able to obtain at least one sample each year over the three year period 2006–2008 for 280 of the Fortune-1000 companies. All companies in this sample used a proprietary operating system for their web client and 97–99% of them used a proprietary web browser. The percentage of the companies of our sample using an open source browser for each of the three years rose from 52% to 70% to 76%, while the percentage of those using an open source operating system rose from 15% to 19% to 24%. Although the small number of years in our sample does not allow us to perform regression analysis on it, the data show *a significant percentage of companies using open source software and a trend of increasing adoption rate*, particularly in the case of an open source browser. Moreover, Fig. 4 shows that the levels of OSS adoption vary considerably across various domains. However, more than 50% of the Fortune-1000 companies in our sample have used an OSS system in five out of the eight SIC (Standard Industrial Classification) divisions we have examined.

Table 5
Statistics regarding historical data.

Question	Sample	$P(E_2)$ (%)	$P(E_1)$ (%)	z-Test $P(P(E_2) > P(E_1))$
Q3	70	72	28	4.2488***
Q2	401	79	21	18.4127***

For the significance of asterisks, see Table 2.

Research Question 2: We examined the dynamic characteristics of OSS adoption by individual companies based on historical data. Specifically, we tried to prove that occurrences of the event E_1: *use and reject an open source system* occurred less frequently than events E_2: *use and accept an open source system*, using the following definitions.

E_1: on year N the company uses a number x of open source systems while on year $N+1$ the company uses y OSS systems and $y < x$.
E_2: on year N the company uses a number x of open source systems while on year $N+1$ the company uses y OSS systems and $y \geq x$.

The statistical results listed in the second row of Table 5 show that 79% of the companies using an OSS system in one year will keep it or add more in the next year, and only 21% retreat, indicating an increasing coverage of applications over time. We used a *z*-test to examine the difference between these proportions which, as it can be seen in the last column, is statistically significant.

We also studied the churn rate of companies adopting OSS by looking at the difference between the average number of OSS systems in use each year, using a *t*-test to check the significance of these differences, again for the available data of the client side (see Table 6). When looking simply at companies for which we have data for all years in the range 2006–2008 we found a significant

Table 6
Number of OSS applications being used per year.

	Year			t-Test	
	2006 (x)	2007 (y)	2008 (z)	(x, y)	(y, z)
All companies	0.68	0.89	1.01	3.54***	1.96*
Companies already using OSS	1.28	1.26	1.31	0.41	1.13

For the significance of asterisks, see Table 2.

rise from one year to the next. If however we restrict our view to companies using at least one OSS application and look for a yearly increase in the number of applications used we do not find a significant change. Thus, we see that in total *there is an overall increase in the number of OSS applications being used, but when we look at existing OSS users there are no significant trends*.

Research Question 3: We investigated whether the adoption of OSS progresses from applications to platforms, in the context of a client's web browser and operating system, based again on historical data. Specifically, we looked at whether application-directed transitions from a proprietary to an OSS operating system (OS) (E_2; see below) are with statistical significance more frequent than wholesale transitions to an OSS client OS (E_1) or platform to application transitions (E_3). For instance, it is more likely for a Microsoft Windows user to install the Firefox web browser and then switch to Linux than to switch to Linux and Firefox in one go.

In particular, we defined the following three events.

E_1 (wholesale transition): on year N the company used an OSS client OS and web browser, whereas on year $N-1$ it used a proprietary client OS and a proprietary web browser.
E_2 (application-directed transition): on year N the company used an OSS OS and web browser, whereas on year $N-1$ it used an OSS browser (which sparked the transition) and a proprietary OS.
E_3 (platform-directed transition): on year N the company used an OSS OS and web browser, whereas on year $N-1$ it used an OSS OS (which sparked the transition) and a proprietary browser. (This is a highly unlikely scenario included for the sake of completeness.)

We located 70 samples on the client side that represented one of the events meaning that on year N the company used a OSS system while on year $N-1$ it used its proprietary alternative. A z-test for the significance of the differences among the samples' events (first row of Table 5) shows that the adoption of OSS progresses from applications to platforms. We found no platform-directed transition evidence (E_3) in our analysis. The application of the dynamic behavior we found will lead to a static picture where companies will use more OSS applications than platforms. This can be seen in Table 4 where, particularly on the client side, the adoption of OSS applications is significantly higher than that of OSS.

Research Question 4: We looked at the question of network effects in OSS adoption using both diagrammatic and statistical methods. An overview of the observed network effects in the adoption of OSS or proprietary software can be seen in Fig. 3. On the diagram's left side a circle indicates companies that used three identical software types: all proprietary (filled circle •) or all open source (empty circle ◦). The specific types are marked by circles on the lines' columns. For instance, the second line from the bottom corresponds to the co-existence (marked by a circle on the left) of an open source (the circle is empty) web client operating system (the column corresponding to the first circle on the line), web server application (second circle), and a web client application (third circle). The thick horizontal lines show the probability of each occurrence, i.e. the probability that a company will use a system C of a specific type (open source or proprietary), if a company uses a system A of one type and another system B of another type.

$$P(C|A \wedge B)$$

The software type combinations shown are not mutually exclusive, because our data may contain evidence that a company uses both proprietary and open source software of a particular kind. This is, for instance, the case in the bottom two rows, which both show with a 100% probability that a company using an open source web client operating system and web server application will also use either a proprietary or an open source web client application.

Through the high concentration of circle markings on the left at the figure's bottom, one can easily observe that various combinations of same types of software (open source or proprietary) are more probable to occur than combinations of dissimilar software types.

We also investigated this question using contingency tables. Having these we performed the appropriate χ^2 distribution test for independence and then used Cramer's ϕ measure to identify the strength of association between OSS applications and operating systems either on the client or on the server side (Table 7). As one would expect, there is no statistically significant relationship between the adoption of an OSS server OS and the adoption of an OSS client OS or a web browser. In contrast there is a statistically significant (α<0.01) relationship between all other adoption scenarios. We do not list the contingency table relationship for proprietary software, because there were very few cases where proprietary systems were never used, and, therefore, the method could not be applied.

Table 7
Statistical results of analysis on contingency tables.

Variables (OSS)	χ^2	p-Value	Cramer's ϕ
Client OS – Server OS	2.30	0.188	0.1198
Browser – Server OS	2.46	0.162	0.1241
Browser – Web server	10.92	1.41×10^{-3}**	0.1605
Client OS – Web server	16.47	8.44×10^{-5}***	0.1971
Client OS – Browser	46.10	2.70×10^{-11}***	0.3109
Server OS – Web server	72.55	5.06×10^{-17}***	0.4458
Browser – more than one	99.12	2.37×10^{-23}***	0.4606
Client OS – more than one	157.28	4.43×10^{-36}***	0.5794
Server OS – more than one	158.21	2.78×10^{-36}***	0.6561
Web server – more than one	297.40	1.21×10^{-66}***	0.6857

For the significance of asterisks, see Table 2.

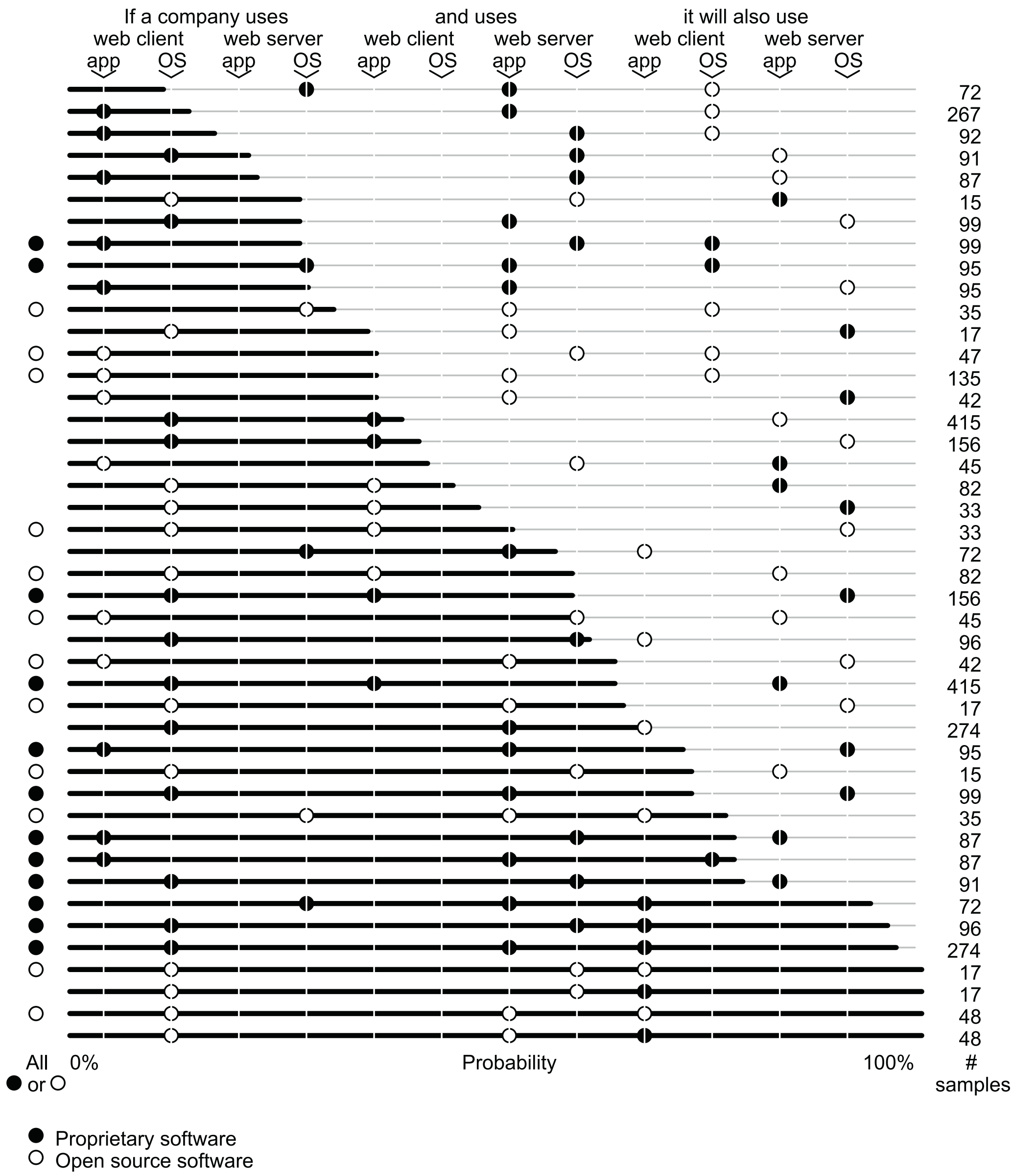

Fig. 3. Network effects in the adoption of OSS or proprietary software.

Furthermore, we drilled down into the relationship between systems by looking at the probability of finding one system, such as a browser or a client OS, given that another was used, either open source or proprietary. We verified the statistical significance of our results with the z-test values listed in Table 8 using a threshold of 50% indicating that a particular adoption scenario can be found in the majority of the companies in our sample. Given this threshold, we found statistically significant relationships (marked with *** in the table) for four cases of particular OSS systems and for all cases of adopting an additional OSS system if one other is adopted. We also found a statistically significant relationship between any proprietary software type and any other. This finding is not as interesting as it sounds; it merely reflects the ubiquity of proprietary systems in all the companies we have examined.

Finally, we searched in our data set for companies for which we have data regarding the use of at least two, three, or four open source or proprietary systems. In each of the three sets we looked at the probability of finding more than one open source or proprietary system in place in at least 50% of the companies. The results appearing in Table 9 show that when looking at three or four software types there is a statistically significant probability of finding more than one OSS system in place (e.g. an OSS browser and an OSS web server). Furthermore, when looking at two to four software types there is a statistically significant probability of finding more than one proprietary system in place. The increase in probability as we look at cases where we know data about more systems is due to the fact that as we include cases with fewer application types in our sample, this becomes less representative.

Consequently, we see that proprietary software and OSS are associated with disjoined network effects.

Research Question 5: We looked at the effect of a company's size on OSS adoption using two types of measures. The t-tests indicated that users of any OSS system have significantly higher revenues and assets than users of proprietary systems (see Table 2). Furthermore, two logistic regression analyses showed a positive relationship between assets or revenues and open source adoption (see Table 3). Focusing on specific OSS systems a number of t-tests showed that companies using an OSS browser, or a client OS, or a web server, have significantly higher revenues than those

Table 8
Adoption relationships between systems.

	y	*x*	$P(\text{Uses}(x)\|\text{Uses}(y))n(\%)$	*z*-Test $n > 50\%$
OSS	Client OS	Browser	100	51.0156***[a]
	Web server	Browser	81	11.5908***
	Server OS	Browser	73	4.3858***
	Web server	Server OS	60	2.2972*
	Server OS	Web server	58	1.8090
	Client OS	Web server	58	1.6368
	Client OS	Server OS	51	0.1770
	Browser	Server OS	44	−1.2401
	Browser	Web server	43	−2.6892
	Web server	Client OS	29	−6.4683
	Browser	Client OS	28	−11.2424
	Server OS	Client OS	26	−4.3858
	Client OS	More than one	100	51.0156***
	Web server	More than one	80	12.3322***
	Server OS	More than one	74	6.1270***
	Browser	More than one	57	3.3574***
Proprietary	Browser	Client OS	100	51.0156***
	Server OS	Client OS	100	51.0156***
	Web server	Client OS	100	51.0156***
	Client OS	Browser	98	51.0156***
	Web server	Browser	97	51.0156***
	Server OS	Browser	96	24.1783***
	Server OS	Web server	86	19.6397***
	Web server	Server OS	84	17.9629***
	Client OS	Web server	64	7.8448***
	Browser	Web server	64	7.7645***
	Client OS	Server OS	60	2.8158**
	Browser	Server OS	59	2.4865*
	Browser	More than one	100	51.0156***
	Client OS	More than one	99	51.0156***
	Web server	More than one	96	51.0156***
	Server OS	More than one	94	35.5233***

For the significance of asterisks, see Table 2.
[a] We use this value as the biggest possible for *z*.

Table 9
Statistics of adopting more than one application of the same type *t*.

	Number of known applications $a_1 \ldots a_k k$	Sample	$P(\exists i, j : t(a_i) = t(a_j))n(\%)$	*z*-Test $n > 50\%$
OSS	At least 2	446	51	0.8906
	At least 3	353	55	2.4606*
	All four	119	63	3.3528***
Proprietary	At least 2	668	94	83.0644***
	At least 3	578	99	182.1667***
	All four	354	100	369.3907***

For the significance of asterisks, see Table 2.

using only proprietary alternatives. Similarly, companies using an OSS web server have significantly higher assets than those using a proprietary web server. Finishing with a logistic regression analysis of specific OSS systems we found a positive relationship between revenues and the adoption of an OSS web browser or a web client OS and between assets and the adoption of an OSS web server OS.

Research Question 6: A correlation analysis between an industry sector's IT capital stock share (Stiroh, 2001) and its corresponding OSS adoption ratio gives a Kendall's τ coefficient of 0.33, which indicates an agreement, though not perfect, between the two rankings.[3] We thus find that the adoption of OSS benefits from a high intensity of IT usage as measured through the IT capital stock share.

Furthermore, Fig. 4 illustrates the level of OSS adoption ratio evidenced by our data across the ten top level SIC divisions. The divisions are ordered by increasing rates of OSS adoption, and one can thus readily observe that OSS adoption is rising with surprising regularity from the diagram's left to the right as a company's focus moves toward the consumer presumably commanding a higher intensity of IT usage.

Research Question 7: We observed statistically significant differences on gross margins and (positive) profits between users and non-users of OSS. Furthermore, we also found significant positive coefficients of the logistic regression (Table 3). We failed to demonstrate a relationship between profits in general (including losses expressed as a negative value) and the adoption of OSS. This is not too surprising, because a company (other than an airline) with losses is in a short-term exceptional state and all bets regarding its strategy and tactics are off. Looking at specific OSS systems *t*-tests analyses show that companies using open source client operating systems have higher gross margins (TTM and five year average) and (positive) profits than those using proprietary alternatives. Companies using OSS browsers appear to have higher profits, while companies running an OSS web server or server OS have significantly higher five year average gross margins than companies running proprietary alternatives. Furthermore, for each of

[3] In order to match with the source's classification we split the manufacturing industry into Durable (SIC codes 20–23, 26–31) and Non-durable (SIC codes 24, 25, 32–39)

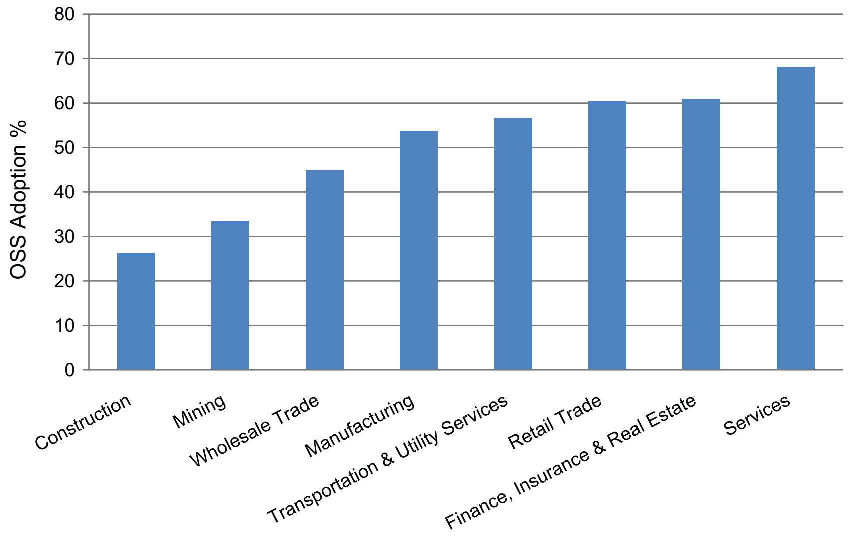

Fig. 4. Evidence of OSS adoption across industries.

the preceding measures logistic regression finds a positive relationship with the adoption of an OSS client OS, a web server, and server OS. Web browser adoption is related only with positive profits, while the adoption of a server OS is also related in a positive way with both the five year average and the TTM gross margin values.

Research Question 8: We tested the organizational stability effect on OSS adoption by performing a *t*-test for means and a logistic regression analysis (see Tables 2 and 3). We used three financial measures as proxies of a company's dynamism: capital spending five year growth rate, sales five year growth rate, and sales TTM vs. TTM one year ago. These indicators measure change, therefore, companies with low values will be unexciting and stable whereas growing and volatile companies will have high associated indicator values.

The *t*-tests indicated that companies using any OSS system have significantly lower dynamic financial indicators than those using proprietary systems (see Table 2) apart from sales TTM vs. TTM one year ago for which this difference existed only for the server side. Also, three logistic regression analyses showed a statistically significant negative relationship between the financial indicators associated with lively, volatile, and growing companies and OSS adoption (see Table 3). Again the same relationship held only for the software on the server side regarding sales TTM vs. TTM one year ago. Focusing on specific OSS systems a number of *t*-tests showed that companies using an OSS web browser or server OS present a lower growth rate of capital spending in the last five years. Similarly, companies that use an OSS web browser or server OS present lower levels of sales TTM vs. TTM one year ago. The logistic regression showed a negative relationship between the five year average capital spending growth rate and the adoption of an OSS web browser or server OS, and between sales TTM vs. TTM one year ago and the adoption of a OSS web server or server OS.

Research Question 9: Again, Fig. 4 indicates that in relative terms OSS adoption is lower in sectors where manual workers are prevalent and higher in sectors where knowledge workers dominate. Similarly, a correlation analysis between an industry sector's knowledge workers share (Wolff, 2006) and its corresponding OSS adoption ratio gives a Kendall's τ coefficient of 0.52, which indicates an even better agreement than that obtained for question 6. Moreover, on the client side, *t*-test and logistic regression show that organizations with knowledge-intensive workers are apt to adopt OSS. The *t*-tests indicated that companies using OSS browsers have significantly higher price to tangible book MRQ while logistic regression showed that there is a positive relationship between this measure and the adoption of both OSS software types on the client side (see tables 2 and 3).

Research Question 10: We examined the relationship between employees' productivity and OSS adoption by looking at the revenue that each employee brings into the company. The statistical analysis listed in tables 2 and 3 indicates that OSS is more likely to be adopted by large organizations with less productive employees.

A number of *t*-tests showed that adopters of an open source browser, client OS and web server produce less revenue for their firm (on a TTM base) while logistic regression proved that the adoption of these software types is also negatively correlated with the revenues over employee TTM figure.

Research Question 11: We tested the pragmatism of OSS adoption choices by looking for zealots: companies that use exclusively open source or proprietary software. We chose sets of companies for which we had data regarding their software choices in the same way as that used in question 4. Table 10 confirms that in the three data sets 61–81% of the companies will mix and match both software types. The raw results are also interesting. In the set of 150 companies for which we have data on all four software systems only 31 companies used just proprietary software, just 11 used OSS for all four software types, and no companies used exclusively OSS. We thus see that organizations will mix and match OSS and proprietary products as needed.

Table 10
Statistics on adoption of both OSS and proprietary software.

Number of known applications	Sample	*P*(use both software types) *n* (%)	*z*-Test *n* > 50 %
At least 2	692	60	10.6668***
At least 3	434	81	22.2601***
All	150	79	9.6187***

For the significance of asterisks, see Table 2.

Table 11
Company examples across research questions.

	Level	Evidence of OSS adoption	Example
IT usage intensity	High	Yes	PSS World Medical
	Low	No	Newmont Mining Corporation
Knowledge intensity	High	Yes	Travelers
	Low	No	Target
Revenue per employee	High	No	Dow Chemical
	Low	Yes	MGM Mirage
Consumer focus	High	Yes	Starwood Hotels
	Low	No	Kiewit

6. Discussion and conclusions

Our results show that the adoption of OSS in large US companies is significant and is increasing over time (Q1) through a low-churn transition (Q2), advancing from applications to platforms (Q3). The adoption of OSS is a pragmatic decision (Q11) influenced by network effects (Q4). The adoption is likelier in larger organizations (Q5) and is associated with IT and knowledge-intensive work (Q6, Q9), operating efficiencies (Q7), and less productive employees (Q10). Table 11 lists scenarios of OSS adoption as indicated by our findings illustrated by examples of conceivable corresponding companies. (Although the examples are consistent with our data, we do not claim statistically validated significance for the specific cases.)

The results associated with question 10 may seem to contradict the answers to questions 6 and 9. One would expect knowledge-intensive workers to be associated with high-revenues per employee and IT usage intensity. However, at least in the context of OSS adoption, we have seen that these are orthogonal measures. There seem to be knowledge-intensive operations with relatively low revenues per employee, such as a call center, which can benefit from OSS adoption. There are also cases, such as in the health industry, where high revenues per employee are not (yet) associated with a relative high intensity of IT usage.

Our findings are broadly in agreement with existing theory on the coexistence of open source and proprietary software in a duopoly (Fig. 3 – Casadesus-Masanell and Ghemawat, 2006), switching costs (Q2 – von Weizsacker, 1984), the advantages enjoyed by platform leaders (Q3 – Cusumano, 2004, pp. 74–77), the drag of earlier technology on IT adoption (Q3 – Fichman and Kemerer, 1993), network effects (Q4 – Katz and Shapiro, 1986), the positive relationship between organizational size and the adoption of innovation (Q5 – Kimberly and Evanisko, 1981), the effect of technical know-how (Q6 – Attewell, 1992), the role of a company's technological experience (Q8 – Dunne, 1994), the risk in IT operations (Q8 – King et al., 1994), the importance of human and knowledge capital (Q9 – Cohen and Levinthal, 1989), and the rationality of corporate social responsibility (Q11 – Clarkson, 1995). Two of our findings add weight to intensely studied organizational IT adoption predictors reported by Jeyaraj et al. (2006). Specifically, organizational size (Q5) has been found to be significant in 8 out of 12 studies, and the IS department size (indirectly examined by Q6) has been found to be significant in 4 out of 7 studies.

On the other hand, we felt that our research was treading on thin theoretical ground in the areas of intra-organizational network effects (Q4), the relationship of IT operations and profitability (Q7), and the effect of an individual's productivity on IT adoption decisions (Q10). These are clearly areas that can benefit from further research. Finally, as one would expect, our study failed to find support that companies follow the ideological arguments associated with the adoption of OSS (Q11 – Gay, 2002).

It would be a mistake for organizations to read our results in a prescriptive manner. The way OSS is currently being adopted does not mean that this is the way OSS should be adopted. A number of companies have successfully used OSS as means of strategic differentiation (Samuelson, 2006; West, 2003). It is quite likely that the majority of successful OSS adoption cases concerns inward-looking IT systems, which our study failed to capture. Even at the tactical level, innovation and progress in the IT industry can well change the way OSS is deployed and used. Following the flock reduces only known risks and will limit opportunities.

Despite the applicability limits of our results, which we outlined in the preceding paragraph, there are some clear lessons that a CTO can learn from this study. OSS is a legitimate technological choice, which is increasingly followed by major US companies. In stable slow-growth environments with a large number of software installations the low purchasing and maintenance cost of OSS can result in savings and thereby increased profitability. Examples include call centers, workstations running just web-based applications, special-purpose platforms, like cash registers and mobile terminals, large server farms, and wide scale deployments of bespoke software with few dependencies on proprietary ecosystems. OSS is not an all or nothing proposition; it can be adopted in a gradual fashion testing the waters for benefits and unknown risks.

Our study's findings are likely to be painful for the OSS community. For many of its members, there are powerful engineering, organizational, and ideological factors acting in favor of OSS (Gay, 2002; Kuan, 2003). Nevertheless, our study found evidence that the open source software's main advantage is its low cost. Where this doesn't dominate a company's financials and purchasing decisions, in rapidly changing demanding areas and environments, proprietary offerings seem to have an edge. Yet, there is no reason for the community to read too much from these findings. For most of its life OSS has thrived in the hands of enthusiasts and hobbyists, away from the limelight of big business. The only who should legitimately worry are those viewing OSS as a foundation for a highly profitable business model. We find it unlikely for somebody to achieve financial success on software that is freely available and that big companies treat as a low priced commodity. In any case, the OSS community has always had an uneasy relationship with the software's commercial exploitation, and in that light our results can be seen as positive.

Furthermore, one finding of our study (Q3) can help the formulation of the Linux community's strategy. This shows that proponents of Linux who try to push OSS from a platform to the desktop may be fighting the wrong war. Organizations are more likely to adopt an OSS operating system if they have already migrated to OSS applications.

Perhaps, the clearest lessons from our study concern the software industry. We showed that in the area of web clients and servers OSS has a large following, and that big companies are increasingly adopting it as they realize its cost benefits in those areas. Software companies that derive a large part of their income from selling standardized products that can be easily replaced by OSS offerings risk seeing their corresponding income stream collapse. Possible remedies include balancing the business between the offering of products and services (Messerschmitt and Szyperski,

2004) and moving toward higher-value, more sophisticated, and tighter integrated products, which we have shown to be less likely to be replaced by OSS.

We were startled by this paper's results. This paper's first author is not a neutral observer, but an OSS advocate. He has written two monographs with hundreds of examples from OSS systems (Spinellis, 2003, 2006), has developed a number of OSS tools, he is contributing to a major OSS project, and has served as a board member of a national academic NGO that promotes OSS. The paper's findings came to him as an unwelcome surprise: the main reason for adopting OSS is lower cost and higher operating efficiencies; OSS appears to be unwelcomed by highly productive employees and in rapidly growing and volatile organizations. Arguments frequently put forward in favor of OSS regarding its flexibility and the retention of technological know-how (Wheeler, 2007) were shattered through findings showing exactly the opposite. Organizations that need flexibility choose proprietary software, as do highly paid employees who could supposedly most benefit by tinkering with OSS to make it fit their needs.

Yet in retrospect the results are not too surprising, if one removes the rose-tainted glasses of romantic idealism and technological optimism. Companies will profit by focusing on their core competencies and by optimizing their operations (Prahalad and Hamel, 1990). There are few reasons to believe that the market would fail to provide them with the software products most suitable for their needs in terms of flexibility, technological sophistication, or ability to adapt software to their specific needs (Attewell, 1992). The market's success will therefore leave cost as the major remaining benefit of OSS.

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