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Opening Up Intellectual Property Strategy: Implications for Open Source Software Entry by Start-up Firms

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We examine whether a firm's intellectual property (IP) strategy in support of the open source software (OSS) community stimulates new OSS product entry by start-up software firms. In particular, we analyze the impact of strategic decisions taken by IBM around the mid-2000s, such as its announcement that it will not assert its patents against the OSS community and its creation of a patent commons. These decisions formed a coherent IP strategy in support of OSS. We find that IBM's actions stimulated new OSS product introductions by entrepreneurial firms and that their impact is increasing in the cumulativeness of innovation in the market and the extent to which patent ownership in the market is concentrated.

Data, as supplemental material, are available at http://dx.doi.org/10.1287/mnsc.2015.2247.

1. Introduction

Although patents play an important "property rights" role in facilitating transactions in markets for technology (e.g., Arora et al. 2001, Gans et al. 2002), the strategic use of patents and the appearance of dense, overlapping webs of property rights known as patent thickets may also work to stifle innovation (e.g., Bessen and Meurer 2008, Jaffe and Lerner 2004, Shapiro 2001). Empirical evidence on this issue is still mixed, with implications varying across industries and firms.[1]

The presence of patent thickets may be a particular issue for developers of information technology (IT) products like computing hardware and software, where innovation is often highly cumulative and products rely on standards of heterogeneous inventions for which patent rights are often owned by many different firms.[2] Firms that wish to mitigate the patent thickets problem can form multifirm institutional arrangements such as standard-setting organizations (SSOs) and patent pools. These mechanisms will lower the transaction costs of identifying and negotiating licensing agreements for related technologies but may also increase the incentives for some patentees to litigate (e.g., Lampe and Moser 2014, Simcoe et al. 2009). As a result, they have had mixed effects on inventive activity that builds upon earlier patented technologies.[3]

Alternatively, firms can use their own patent portfolios, generated internally or acquired through markets for technology, to mitigate risks of infringement posed by patent thickets. This can be done either by making their intellectual property rights (IPR) available to other firms for use at low cost or by facilitating the discovery of prior art for complementary producers who may face litigation. This motivation is widely

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[1] For example, one study on the semiconductor industry finds that the propatent shift in U.S. policy in the 1980s spawned an increase in strategic patenting among capital-intensive firms but also facilitated entry by specialized design firms (Hall and Ziedonis 2001). Cockburn and MacGarvie (2011) find that, following expansions in the patentability of software in the mid-1990s, average entry rates declined, but the likelihood of entry by firms holding patents increased.

[2] For example, Biddle et al. (2010) identify 251 technical interoperability standards in a modern laptop.

[3] For example, Rysman and Simcoe (2008) show that citations of patents increase significantly after disclosure that they are part of a standard, and Lampe and Moser (2010) study the sewing machine patent pool and find that the pool decreased patenting and innovation, particularly among members of the pool.

believed to be one reason for Google's recent acquisition of Motorola. For example, Google CEO Larry Page writes in a letter (Page 2011):

> We recently explained how companies including Microsoft and Apple are banding together in anti-competitive patent attacks on Android. The U.S. Department of Justice had to intervene in the results of one recent patent auction to "protect competition and innovation in the open source software community" and it is currently looking into the results of the Nortel auction. Our acquisition of Motorola will increase competition by strengthening Google's patent portfolio, which will enable us to better protect Android from anti-competitive threats from Microsoft, Apple and other companies.[4]

Despite the potential importance of this type of intellectual property (IP) strategy and its implications for complementary innovation, thus far we have little evidence on whether such actions contribute to increased innovative activity or information about the conditions under which these strategies are most effective.[5] This is an important gap in understanding. In our setting, we will refer to an IP strategy as any of a set of decisions on how to leverage one's own IP in order to stimulate complementary innovation. This could include a patent nonassertion pledge, or the establishment of other institutions to mitigate some of the risks of IPR infringement by complementors. These types of IP strategies are becoming increasingly common in a range of settings, because firms have pledged IP related to such diverse technologies as PC bus architecture and microprocessors (Ethiraj 2007, Gawer and Henderson 2007), open document format standards (Bekkers et al. 2012), electric cars (Musk 2014), and green technology (Hall and Helmers 2013).

Motivated by these observations, we take a first step toward evaluating whether and under what conditions one firm's IP strategy influenced complementary innovation around a set of related platform technologies. Specifically, we study the impact of strategic decisions taken by IBM around 2005 to stimulate innovative activity in open source software (OSS). We use as a proxy for this shift in strategy IBM's announcements of nonassertion of patents against the OSS community and the creation of the Patent Commons (commonly referred to as "The Commons"), a specific set of patents that were made available royalty-free to the OSS community under

certain conditions. We focus on the how these decisions impacted the entry of new products issued under an OSS license (which we refer to as "OSS entry") by U.S. software start-up firms.

We study OSS because it is a setting where the patent thickets problem is thought to be particularly salient; the distributed, incremental development approach to developing OSS implies that innovation is highly cumulative and it is difficult to identify the provenance of source code. As a result, small OSS firms commonly have few patents themselves with which to execute cross-licensing agreements or to facilitate prior art searches when facing litigation (e.g., von Hippel and von Krogh 2003, Alexy and Reitzig 2013).[6] Against the background of this environment, there have been some well-known examples of assertion of IPR against OSS firms (e.g., the *SCO v. IBM* case; see Alexy and Reitzig 2013 and Wen et al. 2013).

Our theoretical framework suggests that IBM's IP strategy in support of OSS should mitigate licensing costs and litigation threats created by patent thickets. Start-ups should expect lower sunk costs of entry than otherwise and thus be more likely to enter into downstream markets. Moreover, we argue that such an IP strategy should have the greatest impact on OSS entry in environments with high licensing and litigation costs, such as when innovations are highly cumulative and when IPR ownership (particularly patent ownership) is highly concentrated.

To test these hypotheses, we gather data on OSS entry by U.S. start-up firms that produce prepackaged software and that are included in the *CorpTech Directory of Technology Companies*. OSS entry was identified using longitudinal press releases contained in the Gale database "PROMT." Our key measure of the extent of IBM's IP support for OSS is based on the number of claims-weighted patents pledged in The Commons in 2005 in each software market. Following prior work that has examined the extent to which patents deter entry into the software industry (Cockburn and MacGarvie 2009, 2011), we allocate patents to software product markets based upon the technological classes of patents and their keywords.

Using count data conditional fixed effects models, our empirical strategy examines whether time series variation in the number of patents contributed to The Commons related to a narrowly defined software market is associated with changes in the amount of OSS entry into that market. Our results show that a 10% increase in The Commons' patent claims in a software market is associated with an average 1%

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[4] Google sold Motorola to Lenovo in early 2014, retaining, however, most of the patents acquired as part of its original deal (Miller and Gelles 2014).

[5] For examples of how openness in IP influences the rate and direction of innovation in academic research, see Murray and Stern (2007) and Williams (2013). Although empirical work on this topic is scant, the perception in the software industry is that bigger companies do not pledge their most important patents (Bort 2010).

[6] Larger firms who offer products under an OSS license frequently do have IPR holdings for complementary technologies that allow them to appropriate value from the OSS activities. For details, see Fosfuri et al. (2008).

to 3% increase in the rate of OSS entry by start-ups into that market. However, introduction of The Commons influences entry, especially in those markets where innovations are highly cumulative and where patent ownership is concentrated. As market cumulativeness increases from the 10th to the 90th percentile, the marginal effect of a 10% increase in The Commons' patent claims on OSS entry increases from 0.6%–1.3% to 4.0%–5.5%. Similarly, as market concentration increases from the 10th to the 90th percentile, the marginal effect of a 10% increase in The Commons increases from 0%–1.7% to 1.5%–2.7%.

IBM's pledge of patents to The Commons in 2005 represented an important shift in its explicit legal support of OSS. However, other events around the same time period also signaled an increase in this type of support. For example, on August 4, 2004, IBM publicly announced that it would not assert its patents against the Linux kernel. These events were clustered between 2003 and 2005, likely representing a response to the SCO Group's lawsuit against IBM in early 2003. This clustering of events makes it difficult to identify the size and significance of each on entry behavior. Consequently, we do not seek to separately identify the effects of The Commons from other elements of IBM's IP strategy, instead treating The Commons as a proxy for IBM's coherent IP strategy in support of OSS. The key empirical advantage of this proxy is that it allows us to identify the patents that are relevant to the activity of OSS developers by technology and—through our concordance—software product segments.

A particular concern for measuring the impact of IBM's IP strategy on start-up entry is that pledged patents could be correlated with unobserved market characteristics or technological opportunities that vary over time. Through a variety of robustness checks, we circumscribe the nature of unobserved heterogeneity that could influence our results. In particular, we show that the effects of IBM's IP strategy do not appear before its lawsuit with the SCO Group; we also show that growth in the number of patents contributed to The Commons is not associated with increased entry from products that should not see entry costs fall, namely products offered under a proprietary license. Last, our baseline results point to the nature of unobservables that would be needed to generate our results; namely, those that appear only in markets with high cumulativeness and concentration.

2. Theoretical Framework

2.1. IP Strategy in a Private-Collective Model of Innovation

Patent thickets are overlapping patent rights that require firms to obtain licenses from multiple patent holders in order to commercialize new technology (Shapiro 2001). They can increase at least three broad types of sunk costs of entry for start-ups: (1) the costs of inventing around existing patents; (2) the costs of infringement, which may include the costs of licensing the infringed technology and the costs of litigation, such as acquiring a defensive patent portfolio as well as injunction and damages; and (3) the transaction costs of acquiring patents owned by others.

Although firms that have a large patent portfolio may be able to navigate the patent thicket through cross-licensing their own patents with those of other IPR holders, this strategy will be harder to implement for small firms appropriating value from OSS. Firms that rely on the OSS community for innovation inputs need to conform to the norms of the OSS developers, who are often philosophically opposed to software patents, considering them antithetical to the spirit of freedom that imbues OSS development (Marson 2004, Schultz and Urban 2012, Stallman 2011).[7] Further, the costs of writing and administering patents may be too high for small firms relative to their benefits. For example, they may have insufficient resources to hire legal staff.

As has been noted elsewhere, incumbent firms with significant patent portfolios and that use traditional appropriability mechanisms to commercialize new technologies in other settings will sometimes also contribute to open source communities under a so-called "private-collective model of innovation" (von Hippel and von Krogh 2003). Under this model, incumbent firms may contribute to public goods such as OSS. Although they may be unable to appropriate value directly from the public good, they may be able to create and appropriate value from complementary products and services such as downstream application software that interfaces with OSS or support for OSS.[8] Although such firms may be able to navigate patent thickets by using their own patent holdings in cross-licensing agreements, the inability of other small firms to similarly navigate the thicket may reduce the extent of complementary innovation and in so doing reduce the value of the public good.

We explore whether a large firm's IP strategy can reduce the costs of patent thickets and so stimulate

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[7] OSS firms may even fear the existence of patents that are even pledged to the community for purely defensive purposes. Although the initial motives may be altruistic, it remains possible that the original patent holder may have a change in strategy; in particular, a change in ownership or management may initiate a change in how patents are used within the organization (e.g., Schultz and Urban 2012).

[8] For example, Fosfuri et al. (2008) find that firms will be more likely to produce OSS products when they have large stocks of complementary patents or downstream complementary capabilities.

complementary innovation. One institutional mechanism that these incumbents can use is to pledge patents for use within the OSS community, that is, to promise not to assert their IPR against products produced under an OSS license. Such patent pledges can be used by large private-collective (p–c) innovators to prevent competing proprietary firms from exercising their IPR against p–c innovation and thereby limiting production of the public good (Alexy and Reitzig 2013). The incentives to pledge increased on March 7, 2003, when the SCO Group filed a $1 billion lawsuit against IBM, asserting some of its copyrighted UNIX software was wrongly copied into Linux by IBM.

These contributions go beyond the requirement that contributors to OSS products automatically grant a license to use, modify, and redistribute contributed code to all other legitimate users of the code. They also extend to complementary technologies that may be used in conjunction with existing OSS products. Besides the foregone profits from not enforcing the patents, if the contributors want to continue using the patents to support OSS but exclude proprietary firms, they would also bear an explicit cost of maintaining and renewing the patents.

Patent pledges can have direct and indirect benefits to the OSS community. For the start-up firms that we study (i.e., those that intend to enter into a market with OSS products), one direct benefit will be the reduction in expected invention and licensing costs related to the contributed technology. Instead of inventing around, start-ups can directly use the technology contributed by incumbents. Moreover, as more patents are made available, it is more likely that the start-ups will use the pledged patents to substitute for protected technologies that may block entry but are not pledged. This sometimes reduces the costs of transacting and negotiating, especially if the blocking patents are held by many different holders. Further, an increase in incumbents' contributions will signal their commitment to generate profits as a p–c innovator through the production of complementary goods and services, rather than through direct enforcement of IPR. Although the contributor retains the right to enforce other patents not included in the contribution, doing so would harm its reputation to the OSS community, decreasing its ability to create and appropriate value as a p–c innovator. As a result, the perceived threat of litigation will decline, or, to use a widespread terminology among software industry practitioners, there will be less "fear, uncertainty, and doubt" (FUD; see Auza 2011).

There may be other indirect benefits. Pledging patents may encourage reciprocal behavior from other industry participants that may benefit p–c innovation (Alexy and Reitzig 2013). For example, other firms involved in p–c innovation may also choose to

pledge patents for use by the community and may acquire additional patent rights to prevent proprietary innovators from acquiring the same and using them against the community. As more patents in a technology area are pledged, it is more likely to create norms of nonenforcement and encourage other p–c innovators' contributions. One way to view this result is through the lens of public good. The contribution of patents represents a commitment not to assert IPR with the goal of fostering the development of new software by entities that are unable to protect themselves against IPR enforcement by traditional means. This goal is more likely to be accomplished when contributions are made by multiple firms. However, in an asymmetric information environment, firms have an incentive to undercontribute (Coase 1960). To provide the public good, actors with high valuations must contribute more than those with lower valuations (Mailath and Postlewaite 1990). In our setting, firms that have large patent holdings and can appropriate more value through complementary innovation would need to contribute more than other firms. Thus, the likelihood of forming sufficient public good of pledged patents will be increasing in the large firm's initial contribution.

An incumbent's IP strategy may include other measures to help other firms to navigate patent thickets and to stimulate complementary innovation. For example, IBM took several measures after the SCO Group filed its initial lawsuit in March 2003. IBM provided a detailed point-by-point answer to SCO's complaint as early as April 2003. It then filed a countersuit against the SCO Group in August 2003, stating in its complaint that "These counterclaims arise from SCO's efforts to wrongly assert proprietary rights over important widely used technology by the open-source community."[9] These actions had broader support within the Linux community (Krazit 2003). Another significant event was IBM Senior Vice President Nick Donofrio's announcement, made on August 4, 2004, that IBM would not assert its patents against the Linux kernel (Scannell 2004).[10] IBM, in collaboration with the Open Source Development Labs, also created an OSS legal defense fund in January 2004 to indemnify customers of OSS who were targeted by the SCO Group (Rooney 2004).

Other major Linux distributors also took action around the same time period. Red Hat filed a lawsuit against the SCO Group, alleging that the SCO Group

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[9] *The SCO Group, Inc. v. IBM*, Civil No. 03CV-0294 DAK, April 20, http://lwn.net/Articles/43592/.

[10] It is believed that this announcement was made in response to a finding by the Open Source Risk Management organization that several large companies, including IBM, held patents that might affect the Linux kernel (Scannell 2004).

spread FUD about Linux and requesting a permanent injunction restraining the SCO Group from representing that Red Hat's Linux products and/or the Linux products of Red Hat's customers and partners violated any of the SCO Group's IP or trade secrets rights.[11].

Similar to IBM, Red Hat also set up a legal fund to defray costs incurred by the OSS community (Novell 2004, Red Hat 2006) and promised to indemnify its customers against litigation related to the use of covered OSS products (Shankland and Kanellos 2003).

In sum, we expect that patent pledges and other IP actions in support of OSS will effectively reduce licensing costs and litigation threats for the OSS community, including the start-ups that intend to enter into a market with new OSS products and their potential customers. These benefits will be increasing in the amount of legal resources that are made available to the OSS community. It is also worth noting that these positive effects on OSS entry will be reinforced as firms enter and produce complementary OSS products. These complementary products would create a platform of interlocking components, which increases the value of OSS products and services to potential buyers and thus would further facilitate entry.

2.2. How the Impact of IP Strategy Varies with Market Characteristics

In the previous section we showed how a firm's IP strategy can promote OSS entry by reducing expected invention costs or by alleviating infringement costs and transaction costs of negotiating with patentees. In this section we explore market circumstances where the effects of such a strategy on reducing entry costs, and so encouraging entry, will be greatest.

A body of literature has attempted to quantitatively characterize patent thickets in specific technology areas and examined their implications for innovation and competition (Hall et al. 2012, von Graevenitz et al. 2011, Ziedonis 2004). We focus on two observable dimensions of patent thickets that influence the ex ante costs of entry. The first is the cumulativeness of innovation, which has been defined as the extent to which an innovator builds on prior developments and discoveries (e.g., Green and Scotchmer 1995, Scotchmer 2004, p. 127). In an environment with high cumulativeness, the boundaries of potential blocking patents are usually blurred. This makes it difficult to build upon existing patents and leads to high costs of inventing around. Further, the presence of many cumulative innovations also suggests high infringement and transaction costs, because start-ups could easily infringe and might need to obtain licenses for a

large set of related patents to enter into a technology space.[12] Therefore, because patent pledges and associated actions could reduce these costs, their effects on OSS entry will be greatest in environments where these ex ante costs are highest, as is the case for environments with cumulative innovations.

The second market characteristic that we study is the concentration of patent ownership within a software market, defined as the extent to which patents are distributed across different holders. Two views have recently been set forth about how patent ownership influences the costs of licensing negotiations. One view holds that increases in fragmentation of patent ownership (i.e., decreases in concentration of patent ownership) will increase the transaction costs of licensing patents, creating an "anti-commons" effect (Heller and Eisenberg 1998). Under this view, when there are many small exclusionary patents held by many firms, the transaction costs of coming to terms with many patent holders will influence a firm's strategic response to potential expropriation risks. For example, firms may patent more aggressively when patent ownership is fragmented (Ziedonis 2004). In sum, under this perspective, the transaction costs of acquiring patents owned by others are particularly high when patent ownership is fragmented.

Recent work has challenged the anti-commons view. Under this view, concentration of patent ownership increases the value of the negotiation for the patent holder, resulting in an increase in incentives to litigate (Galasso and Schankerman 2010, Lichtman 2006). Alternatively, when the innovator needs to obtain licenses from a large number of patentees, the value at stake in each negotiation is smaller, so licensors are less likely to litigate (Lichtman 2006). Galasso and Schankerman (2010) formalize this intuition, showing in the context of a bargaining game that fragmentation reduces the negotiation value of a patent that is potentially infringed and reduces the time to settlement in a patent dispute. In short, under this second view, the expected costs of infringement are highest when patents are highly concentrated, and patent pledges and associated actions in support of OSS will have a particularly strong effect in reducing

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[11] *Red Hat, Inc., v. The SCO Group,* http://sco.tuxrocks.com/Docs/RH/Doc-1.pdf

[12] It is worth noting that the "cumulativeness of innovation" in our context is different from the "royalty stacking" discussed by Lemley and Shapiro (2007). Royalty stacking refers to situations in which a single product potentially infringes on many patents, and thus the royalty rate to one patent holder is affected by the rates to the holders of other patents reading on that product. Although high cumulativeness also suggests that an innovation is built upon many others, it does not focus on the interaction among the potential licensee and many patent holders, and the resulting royalty rate. We will focus on this in the next paragraph: how the ownership of existing patents affects the costs of licensing negotiations faced by a start-up.

entry costs. We will allow the data to inform which of these alternative views shapes our results, and so indirectly contribute to the ongoing debate on fragmentation of patent holdings and litigation risk.

3. Research Setting

As noted above, the context for our study is IBM's IP strategy and its implications for innovation in OSS between 1999 and 2009. IBM's IP strategy over this period is consistent with its overall strategy of support of OSS that started toward the end of the 1990s (Campbell-Kelly and Garcia-Swartz 2009, Capek et al. 2005, Samuelson 2006). IBM initially announced its commitment to Linux in 1999, and in 2001 announced that it would invest $1 billion over the following three years to make Linux more suitable for enterprise applications (Campbell-Kelly and Garcia-Swartz 2009). Since then, IBM has made all of its hardware platforms compatible with Linux, released Linux versions of its software products, and developed Linux-focused service capabilities. IBM explicitly supports OSS to promote open standards in areas that are complementary to its profitable businesses (Capek et al. 2005). Over time, it has focused less on operating systems that might compete with open source alternatives, and focused more on developing and marketing middleware or application software. IBM's business model now focuses on selling high-end hardware, proprietary software running on top of Linux, and systems integration and other customized services to enterprise customers (Samuelson 2006).

As noted above, there are several events that capture IBM's explicit legal IP support for OSS throughout our sample period (1999–2009, as explained below). Although these events are expected to have some value for producers and users of OSS software, most of them are ambiguous about the extent of IBM's commitment to specific software markets. This creates uncertainty for market participants about the value of these commitments, as well as difficulty for the econometrician in measuring the effects of IBM's IP strategy on software markets.

As a result of these ambiguities, we focus on one particular aspect of IBM's IP strategy—its contributions to the Open Source Development Labs' Patent Commons project (commonly referred to as "The Commons"). In January 2005, IBM pledged access to 500 software patents to "any individual, community, or company working on or using software that meets the Open Source Initiative (OSI) definition of open source software now or in the future" (International Business Machines Corporation 2005). Subsequent to IBM's action, several other incumbents pledged an additional 29 patents to The Commons.[13] "Pledge" in

this context means that "patent holders agree they will not, under certain terms and conditions, assert patent rights against third parties who are engaging in activities that might otherwise give rise to a claim of patent infringement."[14] IBM announced in its press release that it believed this was the largest patent pledge of any kind. All pledged patents are explicitly listed in an online public database, and users of the technologies embedded in the patents are not required to sign any formal agreement with The Commons.

Our choice of The Commons as the focus of our analysis is guided by several factors. The Commons specifies contributed patents at a very detailed level, listing each of their patent numbers. Thus, it provides a quantifiable measure of IBM's commitment to different software markets. The Commons is economically important in the sense that it comprises a large collection of patents across multiple software technology markets, allowing us to use variation over time within software markets for identification. Further, The Commons was introduced in 2005, allowing sufficient time to observe changes in entry behavior after its introduction. In short, our focus on The Commons constitutes a measurement strategy for the implications of IBM's IP strategy on innovation in a market.

4. Data

4.1. Sample

Our sample consists of 2,054 start-up software firms from the 2004 and 2010 editions of the *CorpTech Directory of Technology Companies*[15] (denoted as "CorpTech 2004/2010" hereafter) that primarily operate in the U.S. prepackaged software industry. As noted above, the focus of our study is on start-up firms. As a result, we restrict our sample to firms that were founded after 1990 and that have fewer than 1,000 employees and less than $500 million in annual sales.[16] Our sample period is from 1999 to 2009, with 6 years before the establishment of The Commons and 5 years after. We believe this time window is sufficiently long to capture the impact of The Commons on OSS entry.

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[13] Example companies include Computer Associates International, Inc. and Open Invention Network, LLC.

[14] For more details, see http://www.patent-commons.org/resources/about_commitments.php.

[15] Our choice of 2010 CorpTech data reflects a constraint with the data: we have contacted CorpTech and there are no historical data from 2005 to 2009, the core years of our sample period. The combined use of CorpTech 2004 and 2010 data is meant to address potential survivor bias.

[16] If the sample firms are from the CorpTech 2004/2010 directories, the data on year founded, sales, and number of employees we used to identify start-up firms are directly obtained from the CorpTech 2004/2010 directories. Our results are robust to the use of alternative thresholds for inclusion in our sample. For example, our results are robust to an alternative sample of start-ups that includes firms founded after 1990 that have fewer than 500 employees and less than $100 million annual sales.

4.2. Identifying Software Markets and the Matching Patent Classes

We use the product code classification system embedded in the Gale database "PROMT" (Fosfuri et al. 2008) as our primary source to define software markets. Because of certain drawbacks of only relying on the PROMT classifications (we describe these in further detail in Online Appendix A (available as supplemental material at http://dx.doi.org/10.1287/mnsc.2015.2247)), we further match PROMT's software-related product categories with CorpTech's "SOF" product classes to create a PROMT–CorpTech concordance so that each PROMT software product code is associated with a detailed set of keywords. The keywords for each product class are used to (i) manually assign PROMT product codes to PROMT news articles with missing codes and (ii) match software markets with the most relevant patent classes as described below.

An important part of our data construction involves matching product markets to patents. This allows us to identify both the cumulativeness of innovation and the concentration of patent ownership in a software market. As is well established in the literature, this type of matching is difficult (e.g., Griliches 1990, Silverman 1999). We follow Cockburn and MacGarvie (2006, 2011) and match software patents to CorpTech "SOF" product classes to create a patent–CorpTech concordance. Because our software markets are classified through PROMT categories, in order to create the final mapping between software markets and patent classes, we then combine the PROMT–CorpTech concordance and patent–CorpTech concordance to form the PROMT–patent concordance. The final concordance that we use in the empirical analysis consists of 33 software markets matched to 422 patent class–subclass combinations (see Online Appendix A for a detailed discussion of our data construction process).

5. Measures

5.1. Dependent Variable: *OSS Entry*

We measure OSS entry for software market j in year t as the number of events in which start-ups introduce their first OSS product into that market and year. We use a three-step procedure to identify OSS entry in a software market based on the press releases of the 2,054 firms in the PROMT database. First, following the work by Fosfuri et al. (2008) and Bessen and Hunt (2007), we search for a set of keywords within PROMT articles to identify articles related to OSS. Online Appendix A includes the full set of keywords. Second, we manually read all search results that included words from the first step to identify new OSS product introductions. We consider an article as an introduction of a new OSS product when the article indicated that either of the following took place: (i) the

introduction of a new software product that offered one module or more[17] under an open source license (we label such modules "open source modules''); and (ii) the introduction of a new version of an existing software product with open source modules. Third, to identify OSS entry, we keep only the events in which the start-up introduced an open source module into a market in which it did not previously have OSS products. In total, we have 242 new OSS product entry events made by 85 start-up firms from 1999 to 2009.[18] We aggregate these new OSS product entry events by software market and year. The data are structured as a balanced panel. Table 1 includes a brief description of measures and summary statistics for the main variables used in our empirical analysis.

5.2. Independent Variables

5.2.1. *The Commons.* This variable is equal to the log of claims-weighted patent counts in The Commons related to software market j in year t. We use the claims-weighted count to measure the size of The Commons for several reasons. First, since one potential effect of The Commons is to reduce invention and licensing costs for start-ups, using a claims-weighted measure may more precisely capture the scope of technologies contributed by the incumbent. In particular, as noted in Cohen and Lemley (2001, p. 6), "the scope of a patent is defined by its claims, which set out each element of the invention."[19] Moreover, since patent claims reflect an inventor's effort to make the patent more resistant to invalidation challenges (Allison et al. 2004, Bessen 2008), the number of claims may serve as a proxy for patent value. In short, by weighting by claims, we will be able to better capture variance in the value and scope of patents contributed to The Commons. We further take the logged value of this variable to reduce skewness.

5.2.2. *Cumulativeness.* This variable refers to the cumulativeness of innovation within market j in year t. We use patents' backward citations, which provide information about "existing ideas used in the creation of new ideas" (Caballero and Jaffe 1993) and indicate "some form of cumulative technological impact" (Jaffe et al. 1998). Following Clarkson (2005),

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[17] In software, a module is a part of a program. A software product is composed of one or more modules that are linked together but perform different functions (e.g., the calendar module available in Microsoft Office's Outlook).

[18] This procedure implicitly assumes there is no OSS entry by firms before 1999. We believe this assumption is supported by empirical evidence. For example, SourceForge, a major repository of OSS, was started in November 1999.

[19] Although we use patent claims as a proxy for patent scope, we by no means argue that the correlation is necessarily positive. For instance, Allison et al. (2004) suggest that claims may be negatively correlated with patent scope.

Table 1   Summary Statistics

Variable name	Measure (market-year)	Obs.	Mean	SD	Min	Max
Dependent variable						
OSS entry	The number of start-up entry events through releasing new OSS products related to market j in year t	363	0.667	1.349	0	11
Independent variables and controls						
The Commons	Log of The Commons' claims-weighted patent count related to market j cumulated up to year t	363	2.413	2.936	0	7.911
Cumulativeness	Log of cumulativeness of innovation in market j up to year t	363	0.808	0.613	0.095	3.454
Concentration	Four-assignee citation concentration ratio in market j up to year t	363	0.227	0.075	0.076	0.458
Sales growth	The growth of market j's sales from year $t-1$ to year t	363	1.007	0.150	0.631	2.112
Total patents	Log of total claims-weighted patent count related to market j cumulated up to year t	363	10.817	1.232	6.870	13.486
Patent quality	Log of cumulative stock of citations received by the patents in market j (adjusted for truncations) divided by total number of patents in j up to year t	363	2.832	0.402	1.839	4.051
Patent age	The average age of patents in market j granted by year t	363	5.813	1.784	1.956	12.668
OIN patents	Log of Open Invention Network's claims-weighted patent count in market j cumulated up to year t	363	1.125	2.053	0	6.690
SSO patents	Log of standard-setting organizations' claims-weighted patent count in market j cumulated up to year t	363	1.628	2.118	0	5.908
OSS demand	Log of the share of OSS downloads related to market j up to year t (as a measure of OSS opportunities in market j by year t) weighted by the total software sales in year t	363	4.758	2.233	0	9.035

we measure it based on the average propensity for patents in market j and year t to backward-cite patents within the same market j. This is roughly similar to the way economists have measured the cumulative nature of innovation at the firm level, e.g., using the extent to which firms self-cite their own patents (Hall et al. 2005). In our setting, we proceed as follows. If we sort the N patents within a software market j chronologically (with $m = 1$ being the oldest patent and $m = N$ being the youngest), the cumulativeness for each patent n (i.e., the propensity for patent n to cite preceding patents within the same market) is calculated as $C_n = \sum_{m=1}^{N}(x_{nm}/(n-1))$, where x_{nm} is a dummy variable equal to one if patent n back-cites patent m, and zero otherwise (with both patents belonging to the same market), $(n-1)$ is the total number of possible citations, and $n > 1$, since C_1 is undefined. In other words, the cumulativeness of a focal patent in market j is based on the share of potential backward citations to patents belonging to the same market that are actually cited by the focal patent. The cumulativeness of innovation for software market j is then the average of all $N-1$ patents' cumulativeness: $C_j = (\sum_{n=2}^{N}\sum_{m=1}^{N}(x_{nm}/(n-1)))/(N-1)$. This measure varies over time based on the grant year of the market j patents under consideration.[20] Note that the older patents in a market tend to have greater cumulativeness since the

potential number of patents that can be cited is smaller. As a robustness check, we also use an alternative weighting scheme, one that provides relatively lower importance to the cumulativeness measure of older patents. As in Clarkson (2005), it is calculated as $C_j = (\sum_{n=1}^{N}\sum_{m=1}^{N}x_{nm})/(N(N-1)/2)$. For both measures, we take the logged value to reduce skewness.

5.2.3.   Concentration. This variable indicates the extent of concentration of patent ownership in a market. Following Noel and Schankerman (2013) and Cockburn and MacGarvie (2011), we use the four-assignee citation concentration ratio to measure the concentration of patent ownership in a software market. Backward citations indicate the extent to which a technological area has already been covered by prior art, so the share of backward citations owned by an assignee suggests the extent to which the assignee holds existing patented technologies and therefore the importance of negotiating with the assignee. To construct this variable, we first calculate the number of citations made by patents in market j up to year t that are held by the cited assignee n (denoted as s_{njt}). Then we arrange s_{njt} in descending order. The total citations owned by the four firms that received the top four largest number of citations made by patents in market j in year t (i.e., the top four s_{njt}, where $n = (1, 2, 3, 4)$) is $\sum_{n=1}^{4}s_{njt}$. Thus, the four-assignee citation concentration ratio for market j in year t is calculated as $\sum_{n=1}^{4}s_{njt}/total\_citations_{jt}$, where $total\_citations_{jt}$ is the total number of citations made by patents in market j up to year t.[21]

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[20] We acknowledge this measure also captures the extent to which knowledge is focused in a software market, which is slightly different from how cumulativeness of innovation is defined in this study. As a result, there may exist some nuance in interpreting the empirical results based on this measure.

[21] We also use an eight-assignee citation concentration ratio as a robustness check, and the results are qualitatively similar.

5.3. Control Variables

5.3.1. *Sales Growth.* One important factor that may correlate with both IBM's IP actions and OSS entry is the rate of market growth for software market j, which is proxied by the sales change from year $t-1$ to year t in market j. Because we do not have CorpTech data between 2005 and 2009, we use the National Establishment Time-Series (NETS) Database to measure this variable. The NETS Database includes sales from over 100,000 U.S.-based firms with primary Standard Industrial Classification (SIC) code 7372. Approximately 4,500 software firms in the NETS data are assigned to one of the eight-digit SIC categories (e.g., 73729901) that correspond to eight broad categories in the software industry. We compute the yearly sales change for each of the eight SIC categories and then map them to our 33 software markets to approximate the overall sales growth for each market for a given year. Nevertheless, we acknowledge that one shortcoming of constructing *Sales Growth* in this way is that, because some of the broader SIC categories match to multiple markets, we are forced to assume the markets matched to the same SIC have the same growth rate each year.

5.3.2. *Total Patents.* Although we are most interested in two of the most important features of patent thickets, the cumulativeness of innovation and the concentration of patent ownership, the total number of patents related to a market has also been used as a measure of the density of patent thickets (Cockburn and MacGarvie 2011). We add this variable as an additional control and measure it using the cumulative number of granted patents that are not included in The Commons but related to software market j. To be consistent with how we measure The Commons, we use the log of the claims-weighted patent count.

5.3.3. *Patent Quality.* This variable is a control for the quality of patents in market j in year t. As has been noted elsewhere, higher-quality patents suggest superior technological capabilities possessed by existing incumbents in the market, which leaves less room for start-ups to innovate further. This variable is equal to the log value of the cumulative stock of citations received by the patents in market j (adjusted for truncations) divided by the total number patents in j up to year t.

5.3.4. *Patent Age.* Given the way we measure cumulativeness, a market with older patents tends to have higher cumulativeness. Therefore, we compute the average age of patents in market j granted by year t and add this as a control.

5.3.5. *Open Invention Network* (OIN) *Patents.* At the end of our sample period, another institution similar to The Commons—OIN—was established. Similar to The Commons, OIN offers contractually royalty-free usage of its patents to OSS participants as long as users promise not to file suit against software associated with the Linux system. We do not focus on the implications of the introduction of this institution in our main analysis because its late introduction during our sample period made it difficult to devise a statistical test with sufficient power. We measure this variable as the log of the claims-weighted patent count of OIN patents related to software market j cumulated up to year t.

5.3.6. *Standard-Setting Organization* (SSO) *Patents.* As mentioned earlier, another important mechanism to address the anti-commons problem is SSOs. Such institutions promote coordination of innovation by providing a forum for collective decision making among firms, facilitating the introduction of standards (Rysman and Simcoe 2008). If any patent is incorporated into the standards, the patent owner can gain significant power to control the diffusion of such standards and even deter market entry (Shapiro 2001, Rysman and Simcoe 2008). To prevent this blocking effect, most SSOs require patent holders contributing to the standard to license their patents on fair, reasonable, and nondiscriminatory (FRAND) terms. Firms can even choose to license their patents on royalty-free terms. We control for the incidence of SSO patents that are licensed royalty-free because we expect that such patents might also have some effect on OSS entry. Therefore, we collect all patents disclosed under royalty-free licenses by the major eight SSOs (e.g., IEEE, ITU) from 1971 to 2008 (Rysman and Simcoe 2008).[22] We compute the claims-weighted patent count of the SSO patents that are distributed under royalty-free licenses and are related to software market j cumulated up to year t.

5.3.7. *OSS Demand.* Although *Sales Growth* controls for general market growth, the market demand for OSS products may deviate from the demand for proprietary software products. Measurement of economic activity generated by OSS is difficult, because OSS is unpriced and economic value may frequently be generated in service, support, and complementary software production activity (Greenstein and Nagle 2014, Lerner and Schankerman 2010). One potential source of data on the investment and use of OSS would be to use OSS downloads at Source-Forge.net (SourceForge). SourceForge, as the world's largest repository for OSS projects, provides more than 300,000 OSS applications for free download.

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[22] We are grateful to Tim Simcoe and Christian Catalini for allowing us to use their SSO patent data set. These data are available for download under a creative commons license at www.ssopatents.org.

Table 2   **Patents in The Commons Compared to Other Similar Market Patents**

	Patents in The Commons	Other similar market patents	
	Mean (SE)	Mean (SE)	*t*-test
Forward citations as of Dec. 2004	11.393 (0.683)	12.334 (0.788)	−0.903
Backward citations	9.718 (0.314)	9.739 (0.394)	−0.042
Claims	17.321 (0.496)	19.400 (0.686)	−2.458***

Notes. For each patent in The Commons, we randomly selected a control patent from all market patents that matched the primary classification of The Commons patent at the subclass level and that were applied for in the same year or within a one-year window of The Commons patent. The number of observations in each group is 517. To eliminate the possibility that contributions to The Commons may result in an increase in forward citations, we only use forward citations that were received by December 2004 (i.e., before the initiation of The Commons in January 2005). Because 57% of the patents in The Commons were granted before 1998 and 97% of the patents were granted before 2002, we believe that concerns of truncation bias in citations will not be a major issue in this setting.

      ***Indicates significance at the 1% level.

Such OSS applications are usually affiliated with one or more categories such as Business and Enterprise, Software Development, Database, etc. However, because SourceForge downloads are unpriced, they provide little indication of the potential economic value being created and the economic opportunity for entrants. Therefore, instead of using downloads directly as our measure of OSS demand, we use them as a way of weighting total economic activity in software.

In particular, we first manually match the categories defined by SourceForge to our 33 software markets. Based on this matching, we are able to map over 0.2 million OSS applications to the 33 markets. We then measure the share of OSS application downloads related to market j by year t by dividing the cumulative downloads for the OSS applications related to market j by year t by the cumulative downloads for all OSS applications matched to the 33 markets by year t (denoted as *Share of OSS downloads$_{jt}$*). Second, the total economic activity in software in year t is measured by the total sales (in millions) from the NETS database of firms that have primary SIC codes matched to the 33 markets in year t (denoted as *Software Sales$_t$*). Thus, OSS demand for market j in year t is equal to the log of *Software Sales$_t$* multiplied with *Share of OSS downloads$_{jt}$*.

6. Empirical Strategies and Results
As noted earlier, we use IBM's contributions to The Commons as a proxy for its commitment to supporting innovation in OSS. It is important therefore to assess the quality of these contributions. In this section, we first investigate the quality of patents in The Commons relative to comparison groups as well as how IBM allocated its contributions across different markets. We then document the characteristics of software markets that are associated with few or many of The Commons' patents, and examine whether these characteristics differ before and after the formation of

The Commons. Next, we try to measure the effects of IBM's IP strategy by establishing a baseline relationship between OSS entry and the size of The Commons, and we demonstrate how this relationship is influenced by the level of cumulativeness of innovation or patent ownership concentration in a market. We then show that our baseline results are robust to a variety of robustness checks.

6.1. Characteristics of Software Markets and Patents in The Commons
We first compare patents in The Commons to similar market patents. Following the matching method employed by Thompson and Fox-Kean (2005), we pair each patent in The Commons with a randomly selected control patent that matches the primary classification of The Commons' patent at the subclass level and that was applied for in the same year or within a one-year window. As shown in Table 2, there is no statistically significant difference between the two groups in terms of forward citations or backward citations. The patents in The Commons have a lower number of claims than other market patents, suggesting that The Commons may be less resistant to invalidation challenges (Bessen 2008).

We next compare the quality of The Commons' patents contributed by IBM with other patents in IBM's portfolio, using the same procedure described earlier. As shown in Table 3, there is no significant difference in forward citations between the two groups. Consistent with the comparison with similar market patents, the patents in The Commons have a slightly lower number of claims than IBM's other patents. The patents in The Commons also show a lower number of backward citations, which may suggest that these patents are less derivative than comparable IBM patents (Lanjouw and Schankerman 2004). Nevertheless, the lower number of backward citations made by The Commons' patents could also imply that they are more subject to the challenges by prior art they possibly missed (Bessen 2008). In general, these

Table 3   IBM's Patents in The Commons Compared to IBM's Other Similar Patents

	IBM's patents in The Commons	IBM's other similar patents	
	Mean (SE)	Mean (SE)	*t*-test
Forward citations as of Dec. 2004	11.044 (0.784)	10.341 (0.702)	0.668
Backward citations	9.683 (0.358)	11.545 (0.509)	−2.992***
Claims	16.813 (0.501)	18.646 (0.612)	−2.319**

Notes. For each of IBM's patents in The Commons, we randomly selected a control patent from all of IBM's patents that matched the primary classification of the focal patent at the subclass level and that were applied for within a one-year window of The Commons patent. The number of observations in each group is 407. To eliminate the possibility that contributions to The Commons may result in an increase in forward citations, we only use forward citations that were received by December 2004 (i.e., before the initiation of The Commons in January 2005). Because all of IBM's patents in The Commons were granted in year 1993, 1997, or 2001, we believe that concerns of truncation bias in citations will not be a major issue in this setting.

** and *** indicate significance at the 5% and 1% levels, respectively.

comparisons suggest that, although patents in The Commons may be less resistant to invalidation challenges, they have similar quality and may be somewhat less derivative.

To investigate whether IBM's IP support to OSS is consistent with its proprietary IPR portfolio, we then examine the distribution of The Commons' patents pledged by IBM across 33 software markets, and compare it with the distribution of IBM's proprietary patents holdings. Figure 1 suggests the two distributions are quite similar: IBM made the greatest number of contributions to the markets such as operating systems and utilities, disk/file management, and database software, followed by software development tools and system management software. Similarly, IBM's proprietary patent holdings are also concentrated in those markets. In the online appendix we also present data on the extent of cumulativeness and concentration across market segments (Figure B-1 and B-2).

Last, we examine the characteristics of markets where the number of claims-weighted patents in The Commons is small (below the 25th percentile) and where it is large (above the 75th percentile), before and after The Commons was introduced. As reported by Table 4, in markets where The Commons patents are well represented, OSS entry is greater during both the pre-Commons and post-Commons period. However, during the pre-Commons period the sales growth is lower in markets where IBM was about to pledge a large number of patents to The Commons; it became greater in these markets after The Commons was established. In markets where The Commons patent are well represented, cumulativeness of innovation and patent quality are lower, whereas patent ownership concentration and total number of market patents are greater, and these markets also contain younger patents. These differences persist before and after The Commons was introduced.

6.2.   Descriptive Evidence

Before turning to our regression estimates, we first provide some descriptive evidence on patterns of entry in markets characterized by different levels of patents contributed to The Commons. Figure 2 shows that there is significant OSS entry after introduction of The Commons in markets where the number of claims-weighted patents in The Commons is large, whereas there is no change in OSS entry in other markets.

Figure 3 motivates our results, demonstrating differential benefits for The Commons in markets with high cumulativeness and concentration. Figures 3(a) and 3(c) show that there is little growth in OSS entry after the introduction of The Commons in all markets where The Commons has few patents. Figures 3(b) and 3(d) examine growth in entry in markets where The Commons is well represented; Figure 3(b) shows that the introduction of The Commons is associated with greater OSS entry but only in markets where innovation is cumulative, whereas Figure 3(d) shows that growth in entry after The Commons is higher in markets with high IPR concentration.

These results provide preliminary evidence that market segments with a large number of The Commons contributions are associated with greater growth in entry, and this is particularly the case in markets with high cumulativeness and concentration. Of course, these results could reflect unobserved market-specific factors that are correlated both with contributions to The Commons and with OSS entry. For this reason we next turn to our model-based results.

6.3.   Baseline Results and Robustness Checks

Our baseline empirical strategy seeks to establish whether increases in the size of The Commons are associated with increases in OSS entry in related markets. The estimation framework is motivated by recent research that has studied how patent thickets influence market entry in the software industry (e.g., Cockburn and MacGarvie 2011). We model OSS

Figure 1   **Distribution of IBM's Patents in The Commons and IBM's Proprietary Patent Portfolio by Market**
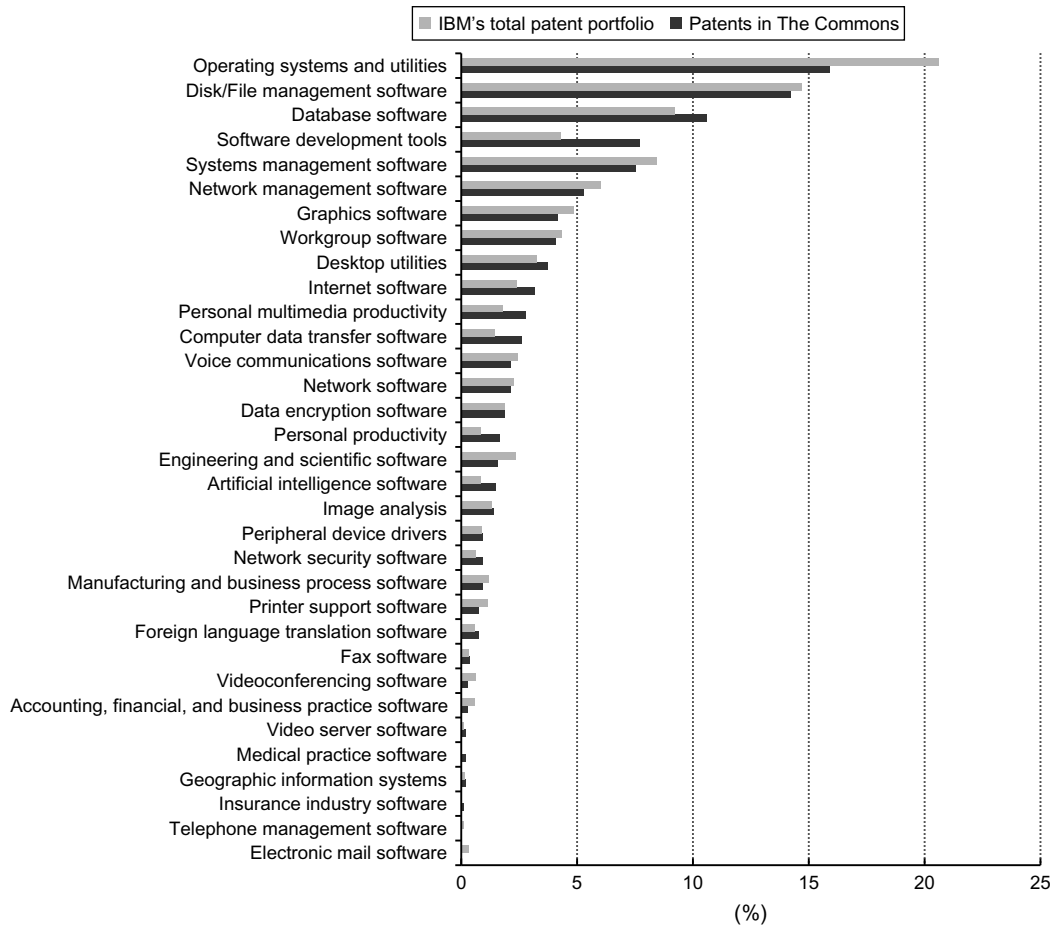
Note. For "IBM's total patent portfolio," the numbers on the horizontal axis are the percent of IBM's proprietary patents that belong to one of the 33 markets in our data; for "Patents in The Commons," they are the percent of IBM's patents in The Commons that belong to one of these markets.

entry using count data models with conditional fixed effects. Suppose the number of OSS entry events in software market j in year t (denoted as Y_{jt}) follows a Poisson process with parameter λ_{jt} taking the form $\lambda_{jt} = \exp(X'_{jt}\beta)$. Also suppose α_j is a market-specific and time-constant variable that incorporates unobserved heterogeneity across markets. Thus, the baseline specification can be written as $E(Y_{jt} \mid X_{jt}, \alpha_j) = \lambda_{jt} = \alpha_j \exp(X'_{jt}\beta)$, where

$$X'_{jt}\beta = \beta_1 The\,Commons_{jt} + \gamma_1 PatentThicket_{jt-1}$$
$$+ \gamma_2 SalesGrowth_{jt} + \gamma_3 MarketPatents_{jt-1} + \tau_t. \quad (1)$$

The vector $PatentThicket_{jt-1}$ includes the two patent thicket variables $Cumulativeness_{jt-1}$ and

Table 4   **Market Characteristics in Pre-Commons and Post-Commons Periods**

	Pre-Commons (1999–2004)			Post-Commons (2005–2009)		
	Markets where The Commons is small	Markets where The Commons is large	*t*-test	Markets where The Commons is small	Markets where The Commons is large	*t*-test
OSS entry	0.278 (0.100)	1.389 (0.273)	3.823***	0.155 (0.055)	1.844 (0.330)	5.045***
Cumulativeness	1.506 (0.107)	0.552 (0.045)	−8.188***	1.091 (0.094)	0.326 (0.029)	−7.745***
Concentration	0.213 (0.011)	0.295 (0.007)	6.729***	0.182 (0.012)	0.256 (0.007)	5.557***
Sales growth	1.051 (0.013)	0.985 (0.021)	−2.616***	0.978 (0.020)	1.041 (0.028)	1.801**
Total patents	9.392 (0.154)	11.262 (0.118)	9.667***	10.286 (0.136)	12.207 (0.115)	10.806***
Patent quality	3.253 (0.054)	3.121 (0.031)	−2.116**	2.665 (0.045)	2.553 (0.026)	−2.156**
Patent age	5.112 (0.254)	4.448 (0.181)	−2.131**	6.495 (0.350)	5.923 (0.165)	−1.475*

Notes. Markets where The Commons is small (large) are those where the number of claims-weighted patents in The Commons is below the 25th percentile (above the 75th percentile). The definitions of these market characteristics are shown in Table 1.

*, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Figure 2   **Average OSS Entry by Claims-Weighted Patents in The Commons**
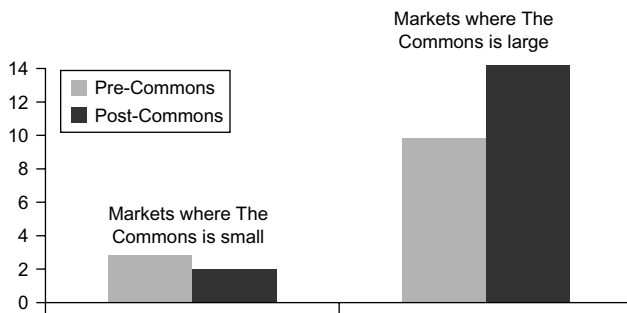
Notes. Markets where The Commons is small (large) are those where the number of claims-weighted patents in The Commons is below the 25th percentile (above the 75th percentile). The Pre-Commons period is 1999–2004; the Post-Commons period is 2005–2009. "Average OSS entry" is the average across all years in the pre- and post-Commons periods. In markets with a large size of The Commons, the *t*-test statistic for the mean difference between pre-Commons and post-Commons OSS entry is 1.313 with *p*-value = 0.1.

$Concentration_{jt-1}$; the vector $MarketPatents_{jt-1}$ includes $Total\ patents_{jt-1}$, $Patent\ quality_{jt-1}$, and $Patent\ age_{jt-1}$. The two vectors are lagged by one year to allow for any lagged effects on OSS entry. τ_t includes 10 year dummies to control for time-varying factors that may influence OSS entry. In the analyses that follow, we will consider the vectors $PatentThicket_{jt-1}$, $MarketPatents_{jt-1}$, and the variable $SalesGrowth_{jt}$ to be our set of baseline controls. Although $OSS\ demand_{jt}$, $OIN\ patents_{jt}$, and $SSO\ patents_{jt}$ may have a significant effect on OSS entry, these variables could themselves be correlated with omitted variables influencing entry. In particular, $OSS\ demand_{jt}$ may be correlated with unobserved market characteristics that encourage IBM to promote OSS development, such as future

growth prospects in OSS or rapid technical change in specific types of OSS. Further, like The Commons, $OIN\ patents_{jt}$ and $SSO\ patents_{jt}$ will reflect efforts by software firms (including, but not limited to, IBM) to lower transaction costs related to IPR infringement and so may be affected by similar concerns about omitted variable bias as The Commons. As a result, these variables are excluded when estimating the baseline results. However, for all of the empirical models employed below, we test the robustness of the results by adding these controls, and the regression results are included either in the paper or in the online appendix.

The baseline specification (1) is estimated using maximum likelihood with robust standard errors clustered at the market level. We are interested in the estimate for β_1, which, if positive, will be consistent with our hypothesis. As noted earlier, we view The Commons as a proxy for IBM's integrated IP strategy in support of open source, and our results should be viewed in that light.

In a perfect world, we could observe how random assignment of IBM patents to The Commons influenced entry across software market segments. Unfortunately, we do not have access to such an experiment. Ultimately, in our setting, IBM chooses both the timing of contributions to The Commons as well as their distribution across markets. As such, our regression estimates represent the equilibrium outcome of IBM's contributions and the entry decisions of software firms. A particular concern, but not the only one, is that IBM may allocate its contributions to software markets that are expected to experience high growth.

We provide additional evidence that is consistent with the interpretation that IBM's IP strategy

Figure 3   **Average OSS Entry by Claims-Weighted Patents in The Commons and Cumulativeness of Innovation/Patent Ownership Concentration**
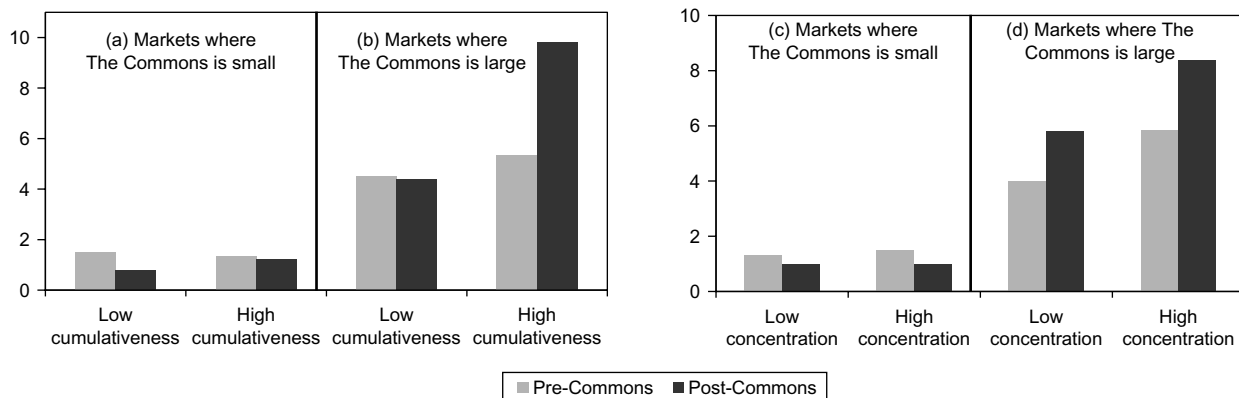
Notes. Markets where The Commons is small (large) are those where the number of claims-weighted patents in The Commons is below the 25th percentile (above the 75th percentile). The pre-Commons period is 1999–2004; the post-Commons period is 2005–2009. "Average OSS entry" is the average across all years in the pre- and post-Commons periods. (3) Low versus high cumulativeness/concentration is defined based on the median split for those variables. For Figure 3(b), in markets with high cumulativeness, the *t*-test statistic for the mean difference between pre-Commons and post-Commons OSS entry is 1.970 with *p*-value = 0.04; for Figure 3(d), in markets with high concentration, the *t*-test statistic for the mean difference between pre-Commons and post-Commons OSS entry is 1.311 with *p*-value = 0.1.

Table 5   Baseline Results, Conditional Fixed Effects Poisson Regression

Dependent variable: *OSS entry*	(1)		(2)		(3)		(4)	
The Commons	0.164*	(0.097)	0.074	(0.151)	−0.115	(0.112)	−0.101	(0.131)
The Commons × *Cumulativeness*			0.323***	(0.096)			0.284***	(0.100)
The Commons × *Concentration*					0.808**	(0.335)	0.513	(0.323)
Cumulativeness	0.372	(1.181)	2.604**	(1.191)	0.210	(1.074)	2.258*	(1.223)
Concentration	−5.901	(6.107)	−10.279*	(5.582)	−11.800	(7.930)	−13.376**	(6.694)
Sales growth	−0.399	(0.327)	−0.553	(0.363)	−0.452	(0.347)	−0.570	(0.365)
Total patents	−0.753	(1.414)	0.668	(1.468)	−1.350	(1.392)	0.151	(1.475)
Patent quality	−0.751	(2.420)	−0.669	(2.345)	−0.568	(2.419)	−0.556	(2.343)
Patent age	−0.293*	(0.178)	−0.253	(0.179)	−0.443**	(0.193)	−0.347*	(0.197)
Log *pseudolikelihood*	−227.183		−223.365		−225.488		−222.760	
Marginal effects								
The Commons (average)	0.164*	(0.097)	0.314**	(0.147)	0.064	(0.074)	0.223**	(0.097)
The Commons (cumulativeness = 10%)			0.135	(0.147)			0.066	(0.107)
The Commons (cumulativeness = 90%)			0.550***	(0.174)			0.431***	(0.126)
Test of the difference between high and low cumulativeness, p-value			0.001				0.004	
The Commons (concentration = 10%)					−0.008	(0.084)	0.178*	(0.103)
The Commons (concentration = 90%)					0.147*	(0.078)	0.276***	(0.099)
Test of the difference between high and low concentration, p-value					0.016		0.112	

Notes. All regressions include year dummies and market fixed effects. Number of observations is 286. This number of observations is lower than 363 because of the use of conditional fixed effects Poisson models, which drops markets without OSS entry over the entire sample period. Robust standard errors, clustered by market, are in parentheses.

*, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

increased the net benefits to entry for potential OSS firms. We augment our regressions with a set of market-specific time trends to control for market growth and other time-varying market-level factors that may be inadequately addressed by our controls. We further study whether the effects of our proxy for IBM's IP strategy, The Commons, appears when and where we would expect if we were to ascribe an interpretation where this strategy influenced entry behavior. We show that the timing of the measured effects of The Commons appears coincident with a series of actions that IBM took in support of OSS and in reaction to the *SCO v. IBM* case in 2003. That is, the effects of The Commons do not appear before the initiation and implementation of IBM's integrated IP strategy. Further, we show that the market segments that are affected by The Commons are consistent with an interpretation of an IP strategy that sought to increase OSS entry. Namely, we show that increases in The Commons are associated with an increase in OSS entry but are not correlated with an increase in similar products offered under a proprietary license. Despite these efforts, we exercise caution when interpreting our results, because we do not possess a true exogenous variable that shifts contributions to The Commons.

Column (1) in Table 5 reports the estimation results for specification (1), which includes baseline controls $SalesGrowth_{jt}$, $PatentThicket_{jt-1}$, and $MarketPatents_{jt-1}$, as well as market and year fixed effects. The coefficient suggests that a 10% increase in The Commons'

patent claims related to a software market is associated with a 1.6% increase in OSS entry in that market.

We next investigate how the relationship between OSS entry and The Commons is influenced by the extent of cumulativeness of innovation and patent ownership concentration in a market. We begin by examining whether an increase in the size of The Commons is associated with a greater increase in OSS entry when the cumulativeness of innovation in a market is high. The baseline specification for $X'_{jt}\beta$ becomes

$$X'_{jt}\beta = \beta_1 \textit{The Commons}_{jt} + \beta_2 \textit{The Commons}_{jt}$$
$$\times Cumulativeness_{jt-1} + \gamma_1 PatentThicket_{jt-1}$$
$$+ \gamma_2 SalesGrowth_{jt} + \gamma_3 MarketPatents_{jt-1} + \tau_t. \quad (2)$$

We note that the nature of identification challenges in this regression is somewhat different than that in Equation (1). Namely, our key identification assumption here is somewhat weaker—that changes in the claims-weighted patents in The Commons are not correlated with unobservable factors that influence entry that are differentially trending in markets with high cumulativeness and concentration. As shown in column (2) in Table 5, a 10% increase in the size of The Commons is associated with a 3% increase in OSS entry, with the effect computed at the average level of cumulativeness of innovation. Further, although an increase in the size of The Commons is not strongly

related to an increase in OSS entry when cumulativeness is evaluated at the 10th percentile, a 10% increase in the size of The Commons is associated with a 5% increase in OSS entry when cumulativeness of innovation is at its 90th percentile. A test for the difference of the two marginal effects (at the 10th and 90th percentiles of cumulativeness) is statistically significant. As described earlier, we also constructed alternative measures of the cumulativeness of innovation, and our results are robust to these changes.

We next explore how patent ownership concentration in a market affects the relationship between OSS entry and The Commons. The empirical results are in column (3) in Table 5. Although The Commons is insignificantly associated with OSS entry when concentration is at its 10th percentile or at its mean value, a 10% increase in the size of The Commons is associated with a statistically significant 1.5% increase in OSS entry when concentration is at its 90th percentile. The test for the difference between concentration evaluated at the 10th percentile and the 90th percentile is statistically significant at the 5% level.

In column (4) of Table 5 we present the results of a specification including the interactions with both cumulativeness and concentration. In these models, a 10% increase in the size of The Commons is associated with a 4% increase in OSS entry when the cumulativeness of innovation is at its 90th percentile; a test of the difference between high and low level of cumulativeness is significantly different at the 1% level. In this specification, although there is no statistically significant difference between the marginal effects evaluated at the 10th and 90th percentiles of concentration, the sign for the interaction between The Commons and patent ownership concentration remains positive across specifications. We suspect this lack of statistical significance is likely caused by the multicollinearity between the two interactions.[23]

We next test the robustness of the baseline results using the following approaches. First, we add additional controls—*OSS demand$_{jt}$*, *OIN patents$_{jt}$*, and *SSO patents$_{jt}$*—to our baseline specification. As shown in columns (1)–(4) in Table 6, the results (both in magnitude and in significance level) are very consistent to the ones in Table 5.

Second, we add to the baseline specification a linear time trend interacted with the market fixed effects to control for time-varying market trends. The results including only The Commons are reported in column (5) of Table 6 and are similar to our baseline result in Table 5, although the economic significance of changes in The Commons is somewhat smaller. We note that the magnitudes of some of the control

variables are significantly different than comparable estimates that excluded the linear time trend variables in Table 5. This suggests that multicollinearity among some of our variables may affect our estimates and that we should exercise some care in interpreting the results using both linear time trends and baseline controls.

We next interact The Commons with cumulativeness as shown in column (6) and with concentration as in column (7). Last, as in Table 5, we add the two interactions together and report the results in column (8). Consistent with the baseline results reported in Table 5, although there is no significant relationship between OSS entry and the size of The Commons when cumulativeness of innovation is at its 10th percentile, a 10% increase in the size of The Commons is associated with a 2.8% increase in OSS entry when cumulativeness is at its 90th percentile, and the difference between the two is statistically significant at the 10% level. Although the size of The Commons is associated with greater OSS entry increase when concentration is at its 90th percentile than at its 10th percentile, the evidence in support of differential effects for markets between high and low concentration is somewhat weaker in these regressions.

As an additional test, in columns (1)–(4) of Table B-1 in the online appendix, we present the results of a model with market-specific time trends but excluding all the controls. We do this because our linear time trends will absorb much of the variation from the baseline controls used in Table 5. The economic and statistical significance of the estimates are qualitatively similar to those in Table 5. We also check the consistency of the results by including both the market-specific time trends and the full set of controls (i.e., including *OSS demand$_{jt}$*, *OIN patents$_{jt}$*, and *SSO patents$_{jt}$*), and we report the results in columns (5)–(8) in Table B-1 of the online appendix. The magnitudes of the point estimates are similar to those in columns (5)–(8) of Table 6; however, the statistical significances of some of the interaction terms are somewhat weaker.

Third, we estimated both the baseline models and the models with the full set of controls using ordinary least squares (OLS) models with market fixed effects. We also substituted our claims-weighted count of the number of The Commons patents in a market with a raw patent count or with a citations-weighted count. Because of the decline in the rate of new OSS product entries after 2006 (as shown in Figure 4), we reestimated the baseline model using a sample endpoint of 2007 and 2008. As detailed in Tables B-2 through B-7 in the online appendix, our results are qualitatively consistent to all of these changes.

Last, because our measure of patent ownership concentration may be confounded with the concentration

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[23] In the pooled sample, the simple correlation coefficient between the two interaction terms is 0.66.

Table 6   Robustness Test Using the Full Set of Controls or Market-Specific Time Trends, Conditional Fixed Effects Poisson Regression

	Regressions that use the full set of controls				Regressions that use the market-specific time trends			
Dependent variable: *OSS entry*	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
The Commons	0.183*	0.102	−0.123	−0.093	0.102***	0.026	0.081	0.020
	(0.106)	(0.154)	(0.139)	(0.178)	(0.031)	(0.065)	(0.135)	(0.160)
The Commons × *Cumulativeness*		0.296***		0.250**		0.171*		0.171*
		(0.098)		(0.107)		(0.102)		(0.102)
The Commons × *Concentration*			0.861**	0.561			0.075	0.021
			(0.383)	(0.440)			(0.451)	(0.512)
Cumulativeness	0.448	2.543**	0.218	2.076	4.731**	4.732**	4.782**	4.746**
	(1.243)	(1.251)	(1.082)	(1.295)	(1.920)	(1.965)	(2.023)	(2.032)
Concentration	−7.400	−11.572	−11.450	−13.488*	16.103**	14.325*	15.497*	14.161*
	(7.750)	(7.667)	(8.392)	(7.717)	(7.612)	(7.625)	(7.997)	(7.923)
Sales growth	−0.303	−0.463	−0.383	−0.487	−0.888	−0.905	−0.888	−0.905
	(0.350)	(0.380)	(0.366)	(0.384)	(0.783)	(0.787)	(0.784)	(0.788)
Total patents	−1.017	0.451	−1.615	−0.146	4.924***	4.805***	4.921***	4.804***
	(1.524)	(1.561)	(1.498)	(1.644)	(1.280)	(1.307)	(1.276)	(1.307)
Patent quality	−1.461	−1.153	−1.250	−1.047	3.754	2.800	3.705	2.788
	(2.385)	(2.307)	(2.287)	(2.247)	(2.770)	(2.851)	(2.842)	(2.939)
Patent age	−0.203	−0.184	−0.325*	−0.263	−0.183	−0.205	−0.177	−0.203
	(0.185)	(0.180)	(0.177)	(0.183)	(0.447)	(0.450)	(0.445)	(0.446)
OIN patents	−0.066	−0.066	−0.071	−0.068				
	(0.072)	(0.066)	(0.070)	(0.067)				
SSO patents	−0.010	−0.016	0.035	0.015				
	(0.082)	(0.069)	(0.088)	(0.084)				
OSS demand	0.306**	0.235	0.312**	0.251*				
	(0.156)	(0.149)	(0.155)	(0.154)				
Market-specific time trend	No	No	No	No	Yes	Yes	Yes	Yes
Log *pseudolikelihood*	−225.095	−222.029	−223.410	−221.414	−214.047	−213.419	−214.042	−213.419
Marginal effects								
The Commons (average)	0.183*	0.322**	0.068	0.217*	0.102***	0.152***	0.098**	0.151***
	(0.106)	(0.153)	(0.086)	(0.130)	(0.031)	(0.031)	(0.044)	(0.047)
The Commons (cumulativeness = 10%)		0.158		0.079		0.058		0.057
		(0.151)		(0.124)		(0.048)		(0.058)
The Commons (cumulativeness = 90%)		0.538***		0.400**		0.277***		0.276***
		(0.183)		(0.173)		(0.095)		(0.101)
Test of the difference between high and low cumulativeness, p-value		0.003		0.019		0.093		0.094
The Commons (concentration = 10%)			−0.008	0.167			0.091	0.149*
			(0.102)	(0.154)			(0.078)	(0.086)
The Commons (concentration = 90%)			0.156*	0.274**			0.105***	0.153***
			(0.082)	(0.114)			(0.033)	(0.035)
Test of the difference between high and low concentration, p-value			0.025	0.202			0.868	0.967

Notes. All regressions include market fixed effects. The regressions for columns (1)–(4) include year dummies. Number of observations is 286. Robust standard errors, clustered by market, are in parentheses. *Market-specific time trend* is measured by a linear time trend times 33 market dummies.

  *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

of market structure, we constructed a measure of market structure concentration using the share of the top four incumbents' sales in each market in each year. As shown in columns (1) and (2) in Tables B-8 and B-9 in the online appendix, we found that adding this measure as an additional control did not affect our baseline finding. Further, we interacted the new market structure control with The Commons variable, in regressions both excluding (columns (3) and (4)) and including (columns (5) and (6)) the interaction of

patent ownership concentration with The Commons. We find that changes in market structure concentration have no significant impact on the relationship between OSS entry and the size of The Commons. Moreover, even when controlling for the effects of market structure, as suggested by columns (5) and (6), an increase in the size of The Commons is associated with a significantly greater increase in OSS entry in markets with high patent ownership concentration. This set of tests supports the view that

Figure 4 OSS Entry from 1999 to 2009, by the Size of The Commons
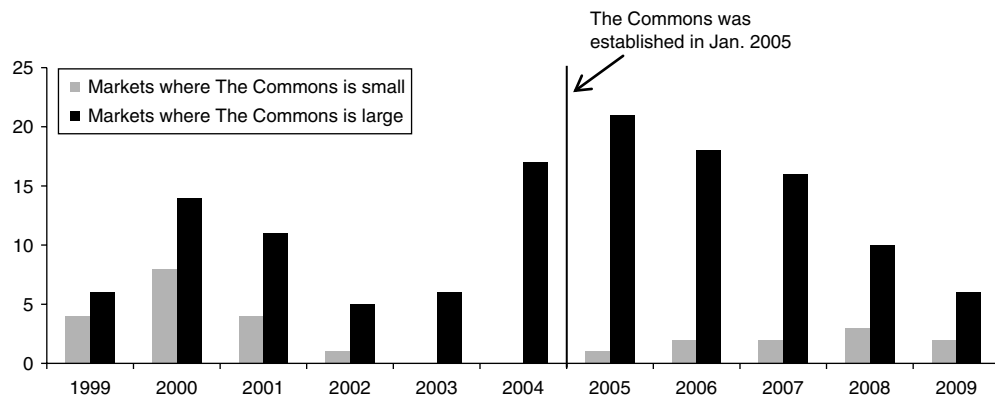
Note. Markets where The Commons is small (large) are those where the number of claims-weighted patents in The Commons is below the 25th percentile (above the 75th percentile).

it is concentration of IP holdings, not concentration of market structure, that shapes the extent to which IBM's IP strategy encouraged OSS entry.

6.4. Exploring the Timing of Benefits from The Commons: The Impact of a Broader Set of IP Actions by IBM

In earlier sections we have noted that we use The Commons as a proxy for the broader set of IP actions that IBM took in support of OSS. Our use of this proxy assumes that the timing and cross-market variance in IBM's overall commitments to open source will be correlated with those that it has made to The Commons. In this section we probe this assumption further. In particular, as noted previously, a close examination of our research context suggests the existence of other decisions taken by IBM in support of OSS shortly before The Commons was established. These other decisions, when combined with its contributions to The Commons, formed a coherent IP strategy in support of OSS.

As mentioned earlier, one significant event in the OSS community during this time period was the March 2003 lawsuit filed against IBM for alleged incorporation of SCO's proprietary UNIX code into the open source Linux operating system. This lawsuit, together with a well-publicized report in 2004 that suggested that Linux was potentially infringing on several hundred patents (Alexy and Reitzig 2013), stimulated a series of actions by IBM that eventually led to the introduction of The Commons and other actions taken to provide additional legal protection for OSS firms. These included IBM's immediate response to SCO's complaint in April 2003, the counterclaims made by IBM against the SCO Group in August 2003,[24] the initiation by IBM of a legal defense

fund for Linux in January 2004, and IBM Senior Vice President Nick Donofrio's announcement that IBM would not assert its patents against the Linux kernel in August 2004.

Figure 4 suggests these actions were associated with an increase in OSS entry. The figure shows the time series of OSS entry for markets with small and large sizes of The Commons. Although there is little variance over time in entry patterns in market segments with few (claims-weighted) Commons patents, markets where The Commons contributions are large see little benefits to entry between 1999 and 2002; however, there is a moderate increase in entry in 2003 and a significant increase in entry in 2004, before the introduction of The Commons but coincident with the SCO case and other legal actions taken by IBM in response to it.

To develop a better understanding on the effects of these various IP actions by IBM, we implement a series of tests and report the results in Table 7. We first confirm the existence of the "pre-trend" by adding the following two variables to the baseline specification: (1) *The Commons in* 2005 × *Year* 04, measured by interacting the value of the variable *The Commons* in 2005 with a time dummy that turns on for year 2004; and (2) *The Commons in* 2005 × *Year* 03, measured by interacting the value of *The Commons* in 2005 with the dummy that turns on for year 2003.

Column (1) of Table 7 shows that the coefficients for *The Commons in* 2005 × *Year* 04 and *The Commons in* 2005 × *Year* 03 are significantly positive, which is consistent with the descriptive evidence summarized in Figure 4. We note that the coefficient that measures the effects of *The Commons* is significantly larger than the baseline effect shown in Table 5, as are the resulting marginal effects. (Note that because we focus on the average effects of The Commons across all markets in this table, the elasticities in the Poisson model can be obtained directly from the coefficient

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[24] All legal case material related to the *SCO v. IBM* case is available at http://sco.tuxrocks.com/?Case = IBM (accessed December 12, 2014).

Table 7 The Impact of a Broader Set of IP Actions by IBM, Conditional Fixed-Effect Poisson Regression

Dependent variable: *OSS entry*	(1)	(2)	(3)	(4)
The Commons	0.442***	0.486***	0.379***	0.411**
	(0.153)	(0.184)	(0.144)	(0.177)
The Commons in 2005 × *Year* 04	0.825***	0.857***		
	(0.202)	(0.216)		
The Commons in 2005 × *Year* 03	0.296*	0.327**		
	(0.158)	(0.141)		
The Commons in 2005 × *Year* 02		0.149		
		(0.191)		
IBM matched patents × *Year* 04			0.429***	0.445***
			(0.118)	(0.126)
IBM matched patents × *Year* 03			0.129	0.146
			(0.120)	(0.117)
IBM matched patents × *Year* 02				0.093
				(0.146)
IBM matched patents			0.145	0.118
			(0.613)	(0.594)
Cumulativeness	−1.382	−1.657	−0.982	−1.117
	(1.265)	(1.326)	(1.265)	(1.281)
Concentration	−10.204	−11.126*	−9.699	−10.221*
	(6.528)	(6.447)	(6.007)	(5.975)
Sales growth	−0.532	−0.535	−0.448	−0.449
	(0.325)	(0.332)	(0.325)	(0.331)
Total patents	−2.723*	−3.006**	−2.789**	−2.953**
	(1.445)	(1.358)	(1.411)	(1.344)
Patent quality	−2.357	−2.546	−2.762	−2.919
	(2.270)	(2.195)	(2.173)	(2.110)
Patent age	−0.387**	−0.411**	−0.282	−0.300
	(0.192)	(0.194)	(0.238)	(0.238)
Log *pseudolikelihood*	−220.059	−219.710	−221.263	−221.039

Notes. All regressions include year dummies and market fixed effects. Number of observations is 286. The results that include the full set of controls are reported in Table B-10 in the online appendix. Robust standard errors, clustered by market, are in parentheses. *Year* 04 (03/02) is a dummy that turns on for year 2004 (2003/2002). *IBM matched patents* is measured by the log of claims-weighted patent count of IBM patents that were not pledged but belong to the same primary USPTO classification at the subclass level as its patents in The Commons and were applied for in the same year.

*, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

estimates.) Column (1) implies that a 10% increase in the Commons is associated with a 4.42% increase in entry; this compares to a 1.64% increase in entry in column (1) of Table 5. This difference reflects the different reference periods against which the coefficient is estimated against: 1999–2004 in column (1) of Table 5 and 1999–2002 in column (1) of Table 7.

We implemented two tests to further explore our hypothesis that this "pre-trend" is a result of IBM's earlier efforts in support of OSS. First, we show that no "pre-trend" exists before 2003, when the SCO case against IBM was filed. We create a variable *The Commons in* 2005 × *Year* 02 and show in column (2) of Table 7 that this variable is small in magnitude and statistically insignificant, which is consistent with our hypothesis about the timing of IBM's actions.

Second, we investigate whether the results in columns (1) and (2) of Table 7 can be explained by an alternative measure of IBM's commitment to OSS. This measure is based on patents that are similar to,

but still different from, the patents that IBM pledged to the OSS community. If our results in columns (1) and (2) are due to legal actions taken by IBM in support of OSS but in advance of the introduction of The Commons, then growth in this measure should similarly be positively correlated with entry in advance of the introduction of The Commons. There are two reasons to expect this. First, if The Commons acts in part as a proxy for IBM's broader commitment to OSS, then a measure based on a similar set of patents should also be positively correlated with entry. Similarly, if IBM eventually signals that it will not enforce its IPR for a specific set of patents in The Commons against OSS firms, then it is likely it also will not enforce its IPR against the set of similar patents.

To identify which patents owned by IBM are relevant to the OSS community in the period preceding the establishment of The Commons, we exploit the distribution of IBM patents contributed to The Commons through a matching procedure (based on the

primary U.S. Patent and Trademark Office (USPTO) classification at the subclass level and application year; see Online Appendix A for further details) and create a new variable *IBM matched patents* for market j in year t using the log of the claims-weighted count of these patents related to market j in year t. Although these patents were not contributed to The Commons in 2005, they were part of the patent thicket potentially threatening the OSS community. Any IP action in support of OSS in years preceding the establishment of The Commons would signal that these patents would not be enforced by IBM against the OSS community. For this reason, we interact *IBM matched patents* with a year 2004 dummy (denoted as *IBM matched patents × Year* 04) and with a year 2003 dummy (denoted as *IBM matched patents × Year* 03) to capture the change in IBM's legal support in defense of OSS during this time of legal uncertainty as a response to the SCO lawsuit in early 2003. To the extent that IBM's efforts in support of OSS reduced the legal threat surrounding the OSS community, these interactions are expected to have a positive effect on OSS entry.

Column (3) of Table 7 presents the results from adding *IBM matched patents × Year* 04, *IBM matched patents × Year* 03, and *IBM matched patents* to the baseline specification. *The Commons* remains significantly associated with OSS entry. The coefficient on *IBM matched patents × Year* 04 is economically and statistically significant but smaller in magnitude than the coefficient on *The Commons in* 2005 × *Year* 04 in column (1). Similarly, *IBM matched patents × Year* 03 is positive but statistically insignificant and smaller in magnitude than the coefficient on *The Commons in* 2005 × *Year* 03 in column (1). In sum, the results suggest that using the patents from IBM's IPR holdings that are not in The Commons displays a similar (although slightly weaker) pattern than directly using patents from The Commons. In column (4), we conduct a test in which we add the interaction of *IBM matched patents* and a year 2002 dummy. The results support our earlier findings that the effect of IBM's IP actions seems to be confined to the post-2003 period.

6.5. Exploring the Markets Where the Benefits of IBM's IP Strategy Occur

We next conduct a falsification exercise to examine whether IBM's IP strategy shows an impact on the "correct" market. Because IBM's IP actions will only benefit producers of OSS, we should not observe a positive effect on entry of proprietary software products. We again use the press releases of the 2,054 startup firms from 2002 to 2009 in the PROMT database to identify proprietary software product entry.[25] We first

manually read all news articles to identify those articles indicating new product introduction events. Next we classified those product introduction events into the 33 software markets. Because we had approximately 12,000 articles about proprietary product introductions, we were unable to use a manual process to classify articles (which differs from the way in which we measured OSS entry in the baseline analysis, where this step was based both on product codes embedded in the articles and manual classification) and instead used only PROMT codes to classify articles.[26] This is likely to be a significant limitation, because 45% of product introduction events are missing PROMT product codes. An additional limitation is that there was a change in the product code classification system during our sample. Between 2007 and 2009, application-related software products were systematically assigned to a higher product code level in the PROMT database. This forced us to group several application markets together, leaving us with 29 software markets, compared to 33 markets in our baseline analysis. Using this method, we have 2,384 proprietary product entry events into 29 software markets from 2002 to 2009.

Given the data limitations on measuring proprietary entry, the results from this section should be interpreted with caution. Nevertheless, we are still able to capture significant variance in proprietary product entry in our sample. The mean number of proprietary entry events per software market per year is 10.276 for proprietary software, compared with a mean number of 0.746[27] for OSS entry identified through both PROMT codes and manual reading and a mean number of 0.134 for OSS entry identified through PROMT codes only.

Our estimation strategy for this analysis is twofold. We first reestimate the models used for Table 5 substituting proprietary entry as the dependent variable. The results are reported in columns (1)–(4) in Table 8. The calculated marginal effect of The Commons when other variables are at mean levels is statistically insignificant across all four columns. The interaction of The Commons with cumulativeness or concentration also has little effect on proprietary entry, as shown by the tests of the difference in

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[25] The press releases we collected from the PROMT database did not include product codes over the period from 1999 to 2001. As

a result, we were not able to classify proprietary entry events into the 33 software markets during this period. Thus, we are forced to focus on the period from 2002 to 2009 only.

[26] We were able to enlist the help of qualified research assistants to help us to manually read articles to identify product introductions. However, classification of the articles across markets was performed by the authors, and we were unable to read the very large number of articles involved.

[27] This mean value is different from the number reported in Table 1, because we focus on years 2002 to 2009 across 29 software markets for this set of falsification tests.

Table 8   **Falsification Test on Product Entry, Conditional Fixed-Effect Poisson Regression**

Dependent variable: Product entry by start-ups	Sample based on proprietary entry only				Sample based on both proprietary entry and OSS entry			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
The Commons	0.077 (0.049)	0.065 (0.065)	0.139 (0.120)	0.126 (0.124)	0.070 (0.048)	0.055 (0.066)	0.130 (0.119)	0.116 (0.124)
The Commons × Cumulativeness		0.021 (0.083)		0.055 (0.065)		0.027 (0.084)		0.062 (0.066)
The Commons × Concentration			−0.163 (0.282)	−0.218 (0.275)			−0.158 (0.280)	−0.219 (0.271)
The Commons × OSS-market					0.270*** (0.041)	0.359*** (0.106)	0.405* (0.231)	0.376* (0.226)
The Commons × Cumulativeness × OSS-market						−0.226 (0.248)		−0.226 (0.314)
The Commons × Concentration × OSS-market							−0.498 (0.779)	−0.039 (1.007)
Cumulativeness	−3.238** (1.346)	−2.910 (1.920)	−3.569** (1.490)	−2.796 (1.903)	−3.164 (1.333)	−2.793 (1.920)	−3.499** (1.477)	−2.677 (1.902)
Concentration	0.856 (4.899)	0.723 (4.986)	2.465 (6.583)	2.652 (6.550)	0.065 (4.637)	0.030 (4.692)	1.742 (6.206)	1.921 (6.152)
Sales growth	0.128 (0.278)	0.131 (0.284)	0.119 (0.287)	0.123 (0.290)	0.102 (0.274)	0.109 (0.280)	0.094 (0.283)	0.100 (0.287)
Total patents	6.234*** (2.117)	6.318*** (2.187)	7.101*** (2.470)	7.624*** (2.526)	6.288*** (2.106)	6.398*** (2.176)	7.134*** (2.424)	7.700*** (2.471)
Patent quality	8.426** (3.730)	8.345** (3.726)	9.466** (3.799)	9.606** (3.831)	8.486** (3.714)	8.423** (3.713)	9.505** (3.760)	9.680** (3.804)
Patent age	0.341 (0.237)	0.351 (0.229)	0.384 (0.275)	0.425 (0.270)	0.346 (0.233)	0.355 (0.225)	0.388 (0.270)	0.430 (0.264)
Log *pseudolikelihood*	−446.067	−446.008	−445.484	−445.128	−496.610	−496.243	−495.954	−495.3435
Marginal effects								
[1] Commons (proprietary market)	0.077 (0.049)	0.077 (0.051)	0.102 (0.066)	0.111 (0.068)	0.070 (0.049)	0.072 (0.050)	0.093 (0.064)	0.103 (0.065)
[2] Commons (OSS market)					0.340*** (0.067)	0.290*** (0.086)	0.382*** (0.092)	0.330** (0.137)
Test of the difference between [1] and [2], p-value					0.001	0.002	0.001	0.042
[3] Commons (proprietary market, cumulativeness = 10%)		0.068 (0.057)		0.089 (0.071)		0.060 (0.057)		0.076 (0.069)
[4] Commons (proprietary market, cumulativeness = 90%)		0.090 (0.076)		0.144* (0.082)		0.087 (0.076)		0.139* (0.079)
Test of the difference between [3] and [4], p-value		0.805		0.398		0.751		0.350
[5] Commons (proprietary market, concentration = 10%)			0.115 (0.084)	0.128 (0.085)			0.108 (0.083)	0.123 (0.084)
[6] Commons (proprietary market, concentration = 90%)			0.088* (0.052)	0.092* (0.055)			0.081 (0.051)	0.087 (0.054)
Test of the difference between [5] and [6], p-value			0.564	0.426			0.572	0.419

Notes. All regressions include year dummies and market fixed effects. Robust standard errors, clustered by market, are in parentheses. Columns (1)–(4) are based on a sample consisting of proprietary entry into 29 software markets from 2002 to 2009, and therefore with 232 observations in total. Columns (5)–(8) are based on a sample consisting of product entry into 29 OSS markets and 29 proprietary software markets. However, 18 markets are dropped because there is no entry observed throughout the sample period; therefore, this sample has 320 observations in total. These results need to be interpreted with caution, as in this exercise we only used entry events (for both OSS and proprietary products) identified through PROMPT articles assigned with product codes. The results including the full set of controls are reported in Table B-13 in the online appendix.

    *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

marginal effects for low versus high values of cumulativeness and concentration.[28] Unfortunately, we are

unable to directly compare the magnitudes of the marginal effects in this table to those in Table 5 because of the different ways of constructing the dependent variable, different sample periods, and the different number of markets. Therefore, to shed light on how OSS entry and proprietary entry might be differentially affected by IBM's IP strategy, our next empirical strategy is to explore the differences in

[28] For robustness, in Table B-11 in the online appendix we also present the results of reestimating the models in columns (1) and (5) of Table 8 using a sample period from 2002 to 2006, excluding the years at the end of our sample where there was a change in the industry coding in the PROMT database. Our results are qualitatively similar using this alternative sample.

product entry across equivalent OSS and proprietary markets.

We define each of the 29 software market categories to consist of both an OSS and a proprietary market, yielding 58 separate markets. Assume that product entry events in market j (where $j = 1, \ldots, 58$) in year t (denoted as $ProductEntry_{jt}$) follow a Poisson process with parameter λ_{jt} taking the form $\lambda_{jt} = \exp(X'_{jt}\beta)$. Also suppose α_j is a market-specific and time-constant variable that incorporates unobserved heterogeneity across markets. Thus, $E(Y_{jt} \mid X_{jt}, \alpha_j) = \lambda_{jt} = \alpha_j \exp(X'_{jt}\beta)$, where

$$
\begin{aligned}
X'_{jt}\beta = {} & \beta_1 \textit{The Commons}_{jt} + \beta_2 \textit{The Commons}_{jt} \\
& \times \textit{OSS-market}_j + \beta_3 \textit{The Commons}_{jt} \\
& \times \textit{Cumulativeness}_{jt-1} + \beta_4 \textit{The Commons}_{jt} \\
& \times \textit{Cumulativeness}_{jt-1} \times \textit{OSS-market}_j \\
& + \beta_5 \textit{The Commons}_{jt} \times \textit{Concentration}_{jt-1} \\
& + \beta_6 \textit{The Commons}_{jt} \times \textit{Concentration}_{jt-1} \\
& \times \textit{OSS-market}_j + \gamma_1 \textit{PatentThicket}_{jt-1} \\
& + \gamma_2 \textit{SalesGrowth}_{jt} + \gamma_3 \textit{MarketPatents}_{jt-1} + \tau_t. \quad (3)
\end{aligned}
$$

The dependent variable in this specification, *Product-Entry$_{jt}$*, is then measured using both proprietary entry and OSS entry. To ensure consistent definitions of product entry across markets, we calculate OSS entry into the same 29 aggregated markets, measured using articles with PROMT codes only; we do not use manual coding for OSS markets in these regressions, and so the mean number of entrants per market-year is lower in this table than in Table 5. The dummy variable *OSS-market$_j$* is equal to one if a market j is an OSS market. We are most interested in the effects of The Commons at mean values of cumulativeness and concentration; if changes in The Commons are associated with a statistically significant increase in OSS entry but not proprietary entry then this is consistent with the framework in this paper. In columns (6)–(8) of Table 8 we also present results of the interactions with cumulativeness and concentration. However, because of the sampling restrictions detailed above, there is far less variance in OSS entry to identify the interaction terms in these models. As a result, statistical inference for the parameters β_4 and β_6 is limited. We present further details on these limitations in Table B-12 in the online appendix.

Column (5) of Table 8 presents the results of model (3) without the interaction terms. Although we do not observe changes in The Commons associated with changes in entry in proprietary markets, a 10% increase in the size of The Commons is associated with a 3% increase in entry for OSS markets, and the difference between the calculated marginal effect

for OSS markets and proprietary markets is significant at the 1% level. Columns (6)–(8) then add the interaction with cumulativeness, with concentration, and with both. As in column (5), at mean values an increase in The Commons is not associated with an increase in proprietary entry; however, the marginal effects of The Commons on OSS entry remain positive and statistically significant in all specifications and are significantly different (in a statistical and economic sense) from the marginal effects on proprietary entry. Consistent with columns (2)–(4), the computed marginal effects suggest that in proprietary markets we do not find any significant difference between low and high cumulativeness, nor between low and high concentration. Although we do not report it in the table because of the limited space, there are no statistically significant differences in the marginal effect of The Commons on OSS entry between markets with high and low cumulativeness, nor for markets with high and low concentration. As anticipated above, our ability to make differential comparisons between proprietary and OSS markets for markets with high and low cumulativeness and concentration is also limited by our data in this sample.

7. Conclusions

In this study we provide evidence on the effectiveness of a large firm IP strategy in support of OSS. We focus on IBM's creation of The Commons in 2005 as a proxy for its IP strategy and examine the implications for entry of new products by software start-ups with an open source license. We show that increases in the size of The Commons related to a software market are associated with increases in OSS entry by start-up software firms in that market. We observe a particularly strong relationship between the size of The Commons and OSS start-ups' entry in markets with high cumulativeness of innovation and also when patent ownership is concentrated.

We provide evidence that the creation of The Commons is one of several IP-related actions taken by IBM to support OSS firms, some of which precede the creation of The Commons. Some of these other actions are clustered in time around the creation of The Commons, challenging our ability to disentangle the effect of each action separately. However, the data show that these actions taken together had a significant impact on OSS entry, suggesting that opening up the IP space is an effective mechanism to stimulate start-up innovation in settings characterized by patent thickets and cumulative innovation.

Our study has implications for our understanding of the impact of formal IPR on OSS, an area in which our knowledge is still quite limited (Lerner and Tirole 2005, von Hippel and von Krogh 2003). Despite the

rapid growth in the commercialization of OSS,[29] OSS contributors and users are easily targeted by holders of IPR because of the cumulative nature of the development process and the difficulty in identifying the provenance of source code ownership. The existence of fear, uncertainty, and doubt (FUD) arising from the threat of litigation will be important for the commercialization of OSS. This research advances our understanding of how the existence and exercise of formal IPR influences the rate and direction of OSS innovation (Graham and Mowery 2005, Lerner and Tirole 2005, Maurer and Scotchmer 2006). This study also sheds some light on recent work that studies firm decisions to appropriate value from OSS (Bonaccorsi et al. 2006, Fosfuri et al. 2008).

Relatedly, our research has important implications for technology management. Firms who donate their IPR forgo potential opportunities to license their IPR in hopes of increasing innovative activity that will spur demand for complementary products and services from which the contributor can appropriate value. The implications of such donations resonate in a broad set of industries beyond OSS. For example, in 2014 electric car manufacturer Tesla Motors offered open licenses to its patents in hopes of promoting complementary innovation in electric cars. Tesla CEO Elon Musk's rationale for this move reflects the platform competition between electric and gasoline-powered automobiles, saying "Our true competition is not the small trickle of non-Tesla electric cars being produced, but rather the enormous flood of gasoline cars pouring out of the world's factories every day" (Musk 2014). Firms such as IBM, Sony, Bosch, and DuPont have similarly pledged patents to an "Eco-Patent Commons" to promote innovation in green technology (Hall and Helmers 2013).

If these contributions do not lead to complementary innovation, then the benefits to contribution will be isolated to the positive publicity in the OSS community. Our results show that such contributions will have an effect on commercial activity in OSS, particularly in markets where patent thickets are most likely to raise ex ante entry costs.

Our findings also inform recent work on the impacts of patent thickets on start-up entry (e.g., Cockburn and MacGarvie 2011). Unlike large firms, start-ups usually lack the R&D capabilities and financial resources required to expand their own patent portfolios, so it is difficult for them to navigate patent thickets using other approaches such as cross-licensing agreements.[30] Our results are consistent with

recent findings that the commercialization strategies of start-up firms are sensitive to the distribution of IPR in the market (e.g., Gans et al. 2002, Huang et al. 2013). Further, although the patent thickets problem can be examined from different perspectives, we highlight the roles of cumulativeness of innovation and patent ownership concentration as two different and important dimensions of patent thickets. We propose mechanisms under which these characteristics may interact with patent commons to determine start-up entry costs. Our research also provides empirical evidence that the IP strategy of a single firm may be one mechanism, in addition to multilateral institutions such as patent pools or SSOs (Shapiro 2001, Rysman and Simcoe 2008), to effectively mitigate the anti-commons problem.

Our study is subject to limitations. One particular concern is how our results may be influenced by time-varying unobservables that can affect both OSS entry and contributions to The Commons. Although we demonstrate that our results are robust to a range of analyses, we acknowledge that our empirical results may reflect different mechanisms through which The Commons and IBM's integrated IP strategy may influence entry. First, the technologies contained in The Commons may directly reduce invention and licensing costs for start-ups. However, another mechanism is that IBM's actions may provide a signal for its broader efforts to protect OSS developers from litigation risks. We do not explicitly disentangle these different mechanisms, but we believe this is an important question for future study.

Our study also points to many other opportunities for future research. In particular, we analyze the impact of an incumbent's IP strategy on the behavior of those firms for which entry decisions are most likely to be affected by the change in licensing and negotiation costs: start-up firms considering entry as an OSS competitor.[31] This type of IP strategy may have secondary implications for two groups of firms that we do not study: large firms involved in p–c innovation and those who sell software under a traditional proprietary license. Understanding the implications of patent commons and associated IP actions by incumbent firms on these other groups will have important implications for the rate and direction of

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[29] For example, Broersma (2007) indicated that worldwide revenue from commercializing OSS reached $1.8 billion in 2006 and was expected to reach $5.8 billion in 2011.

[30] As noted by Matt Asay, the chief operating officer at Canonical (the company behind the Ubuntu Linux operating system), "this

[type of patent collective] may be the only refuge for start-ups and others, like Red Hat, that don't have an aggressive patent-acquisition policy" (Asay 2010).

[31] A natural and interesting extension to this study is to look at how the size of The Commons influences the survival rate of start-up firms producing OSS products. However, of the firms introducing new OSS products in our sample, only one firm exited before the end of the sampling period. As a result, there is insufficient variance in our data to measure the impact of The Commons on the survival of start-up firms who produce OSS.

inventive activity in software. We hope our findings stimulate additional research in this important area.

Supplemental Material

Supplemental material to this paper is available at http://dx .doi.org/10.1287/mnsc.2015.2247.

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