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Commercial versus open source software: the role of product heterogeneity in competition

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Abstract

The emergence and market success of Linux in recent years has been impressive. The paper investigates the question of why some producers of a proprietary software support the development of open source software (OSS) while others refuse any support. As an analytical framework, a simple Launhardt–Hotelling model is used to show that the emerging price pressure on the former monopolists depends on the extent of the current heterogeneity between OSS and the proprietary software of the incumbents. The paper argues that the product heterogeneity can explain the differing real-world behavior of commercial software producers.

JEL Classification: L86; L11; L13

Keywords: Open source software; Commercial software; Product heterogeneity; Competition

1. Introduction

Schumpeterian creative destruction suggests that, eventually, even the most secure monopoly will be 'destroyed' by a new technology, a new idea, or a shift in tastes (Schumpeter, 1934). This paper argues that successful open source software (OSS) projects, developed by volunteer programmers, pose such a threat of 'creative destruction' to proprietary software producers.

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Table 1
Market share for server operating systems, units sold in percent

Operating system	1994 (%)	1995 (%)	1996 (%)	1997 (%)	1998 (%)	1999 (%)	2000 (%)	2001 (%)	2002 (%)	2003 (%)
WindowsNT	7.0	18.1	25.6	35.3	38.3	38.1	41.0	41.5	41.1	41.9
Novell	39.6	34.7	32.1	26.7	22.8	19.1	16.0	11.7	9.9	8.1
Linux	0.0	0.0	6.5	6.8	15.8	24.8	27.0	33.4	36.0	38.0
Unix	28.6	25.4	20.1	20.9	18.8	15.5	14.0	11.6	11.0	10.0
Other	24.8	21.8	15.7	10.3	4.3	2.5	2.0	1.8	2.0	2.0

Source: International Data Corporation [http://www.idc.com] and Brian S. Silverman and Mark Rosenberg, ''Sun Microsystems Inc.: Solaris Strategy'', HBS (8 February 2001): 9-701-058, author's enquiries.

The production of complex software products incurs immense development costs, making software production a fixed-cost business in which the variable costs are virtually zero.[1] Thus, market segments for complex software products tend to take the form of a natural monopoly, where decreasing average costs act as barriers to entry. Because of this, competition in software markets for complex software products is rather rare. With the emergence of reliable OSS products, the market situation has changed fundamentally.[2] OSS projects have proven to be serious competitors for proprietary software products, as the 'entry barrier' of decreasing average costs is ineffective for them. The most famous example is the market for server operating systems.[3] Before OSS, a single dominant enterprise provided the required server operating system for every hardware platform (e.g. Intel, MIPS, and Sparc);[4] there were only a few unsuccessful attempts by commercial software producers to enter one of these various market segments (e.g. OS/2 for Intel-based platforms and WindowsNT for DEC's Alpha processor platform). Recently, however, the OSS Linux has been able to successfully enter the market for server operating systems. According to the International Data Corporation (IDC), by 1999, Linux was already in second place behind Microsoft's WindowsNT in the market segment for server operating systems (Table 1).[5]

A major reason for this successful entry has been that the costs for developing Linux are carried by volunteer programmers. Thus, the consumer is entirely spared of paying for product development.[6] This gives Linux distributors a significant cost advantage over the incumbents.

So far, the R&D literature has not addressed the impact of emerging competition in a fixed-cost business caused by firms with zero R&D costs.[7]

[1] cf. Blackburn et al. (1996), pp. 1–2.

[2] Other entry barriers, such as network effects, technology advantages, etc., can be lifted by corresponding investments which, however, again increase the cost advantages of the incumbent.

[3] Another example is the market for web server software.

[4] The only exception is the market segment for Intel-based servers, where two software enterprises – Microsoft and Novell – offered operating systems.

[5] Information on the Internet site of IDC, URL: [http://www.idc.com] date: 13 March 2000.

[6] For a discussion of the motives of volunteer programmers for working on OSS projects, see Lerner and Tirole (2002), Raymond (2000a, b), and Bitzer et al. (2004). As pointed out by an anonymous referee, one major reason for developing OSS – and thus bearing the development costs – is the benefit to be gained from using the finished software. This is known as the user–programmer motive (see e.g. Kuan, 2001).

[7] For overviews of these topics cf. Tirole (1988) (Chapter 10), Waldman and Jensen (2000) (Chapter 13), and Aghion and Howitt (1998) (Chapter 14).

A wide array of studies in the economic literature have dealt extensively with the question of the incentives and motivations that lead OSS programmers to work at no pay—see e.g. Lerner and Tirole (2002), Johnson (2002), Raymond (2000a, b), Myatt and Wallace (2002), Mustonen (2003), Krogh and Hippel (2003), Hars and Ou (2002), Hertel et al. (2003), Lakhani and Wolf (2003), Bitzer and Schröder (2005), Bitzer and Schröder (2003), and Bitzer et al. (2004). In contrast to this substantial body of literature, very few studies have examined the competition between proprietary and OSS. To the best of my knowledge only four papers, by Kuan (2001), Bessen (2004), Schmidt and Schnitzer (2003), and Casadesus-Masanell and Ghemawat (2003) have addressed this issue. Kuan (2001) analyzes the competition between proprietary and open source software by modelling the decision of agents choosing between buying software and producing it. Bessen (2004) shows that in the case of complex products, the provision of software as OSS is more efficient than the provision as proprietary software. The paper by Schmidt and Schnitzer (2003) asks whether the characteristics of the software market lead to market failures that would justify state intervention. The paper most closely connected to the topic of the present paper is that of Casadesus-Masanell and Ghemawat (2003). They analyze the competition between OSS and proprietary software in a dynamic mixed duopoly with demand-side learning. While in the case of Casadesus-Masanell and Ghemawat (2003), the survival of the for-profit firm is based on the existence of network effects on the demand side, this paper takes a different approach, assuming heterogeneity between the proprietary software and the OSS.

I propose a simple Launhardt–Hotelling model in which one firm, hereafter 'the Linux firm', bears zero R&D costs, while the other firm bears significant R&D costs. The model is used to analyze a series of quasi-duopoly scenarios in which, for every hardware platform, a single dominant firm provides the required operating system. It is shown that the emerging price pressure on the incumbent depends on the extent of heterogeneity between Linux and the incumbent's operating system and thus ultimately on customers' preferences. The absence of development costs for the Linux firm may induce the incumbent to stop any further development of its operating system once the extent of product differentiation no longer permits coverage of average costs. This in turn would result in the collapse of the respective market segments, as new entrants offer only services related to Linux.[8]

The paper is structured as follows. Section 2 describes the recent emergence and development of Linux and the business model of 'Linux firms'. Section 3 introduces a Launhardt–Hotelling oligopoly model to analyze formerly monopolistic markets confronted with competition from a 'Linux firm' entrant. Section 4 provides some evidence on real-world behavior in different market segments. The last section concludes.

2. The case of OSS entry into the server operating system market

In this section, I briefly discuss the case of Linux entering the markets for server operating systems previously dominated by commercial software enterprises.

[8] For hints at further economic implications of Linux cf. Schrettl (2000).

Table 2
Development of Linux 1991–2000

Year	Version	Users	Lines of code
1991	0.01	1	10,000
1991	0.10	100	18,000
1992	0.96	1,000	40,000
1993	0.99	20,000	80,000
1994	1.0	100,000	180,000
1995	1.2.0	500,000	310,000
1996	2.0.0	1,50,0000	780,000
1997	2.0.2x	3,500,000	800,000
1998	2.0.3x	7,500,000	1,500,000
1999	2.2.0	12,000,000	1,800,000
2000	2.4.0	18,000,000	3,380,000
2002	2.5.37	23,400,000	5,100,000
2003	2.6.0	30,420,000	6,000,000

Source: McHugh (1998), information from SuSE, author's enquiries, e.g. information on [http://www.win.tue.nl/~aeb/linux/lk/lk-1.html].

2.1. The short history of Linux

Linux was 'born' in August 1991 when Linus Benedict Torvalds,[9] then a 21-year-old student at the University of Helsinki, made his Linux kernel 0.01 available on the Internet. Torvalds' aim was to create a UNIX-style operating system for his AT-386 PC. From the beginning, Torvalds distributed his source code freely and found an interested hacker community that supported the development of Linux. Since its inception, Linux has been developed by volunteer programmers worldwide via the Internet, where it can also be downloaded for free. After a few years, as a niche product intended for advanced users, Linux has established itself in the software market, particularly in the market for server operating systems. Whereas in 1991 the kernel was very limited in its use; Version 0.12 released in January 1992 already provided a stable, smoothly functioning kernel.[10] In March 1994, the first 'official' version, Linux 1.0, was announced by Torvalds.[11] Table 2 shows the rapid development of Linux in terms of estimated users and written lines of code.

Another indicator for Linux's rapid and successful development is the range of hardware platforms supported, as shown in Table 3.

2.2. Business models connected with Linux

The decision of several large IT companies such as IBM, SAP, Oracle, and Siemens to offer professional support for Linux shows that it has reached a level of quality suited for use in professional business applications.

[9] cf. Torvalds (1999).
[10] cf. Moody (1997).
[11] cf. [http://www.linux.org] and [http://www.linuxinfo.de]. The current version of the kernel is 2.6, with further development underway. cf. [http://www.linuxhq.de] , [http://www.kernel.org], and [http://www.kernel-notes.org].

Table 3
Hardware platforms supported by Linux

Manufacturer	Processor
AMD	K5, K6, Athlon (32 bit and 64 bit versions)
ARM	ARM Thumb family
Compaq	Alpha AXP
Cyrix	386, 486, 6x86
Hewlett Packard	PA-RISC
Hitachi	SuperH
IBM	PowerPC (32 bit and 64 bit versions), RS65 SMP III
IDT	IDT C6
Intel	i386, i486, Pentium series, Celeron, IA-64, i960 family
Macintosh	PowerPC (32 bit and 64 bit versions)
MIPS Technologies	MIPS family
Motorola	PowerPC (32 bit and 64 bit versions), DragonBall family, ColdFire family, Motorola 68000 (Atari ST, Amiga)
NEC	V950 family
Sun	SPARC, UltraSPARC

Source: Information on [http://www.kernel.org].

Linux's GNU General Public License[12] (GNU GPL) guarantees free access to and use of Linux's source code as well as free distribution of Linux to anyone interested. Despite the free distribution, two commercial business models have emerged in connection with Linux. The first type of enterprise offers Linux users services such as installation and configuration assistance, including 24-h hotlines, as well as the compilation and development of current OSS and solutions for Linux. These firms, which operate on a highly competitive market with free entry, are the 'Linux firms' considered in the model.[13] The second type of enterprise expands its product range to include Linux (e.g. SAP offers its business software R3 for Windows, several UNIX variants, and now also Linux). Many of these enterprises do not lose revenues by supporting Linux because they do not develop their own operating systems. But this group also includes companies that support Linux even though they sell their own proprietary operating systems. These are the 'incumbents' in our model, because they occupy a monopoly position in their platform segment prior to the entry of Linux. Their behavior will be analyzed in the next section.

3. The model

As already stated, the production characteristics of complex operating system software imply a tendency towards the emergence of natural monopolies. With the emergence of the multi-platform operating system Linux, the situation has changed fundamentally. As volunteer programmers carry the development costs for Linux, these costs are not passed

[12] cf. Website of the Free Software Foundation at [http://www.fsf.org/copyleft/gpl.html].

[13] One of the largest distributors, SuSE Linux AG, obtained 70% of its revenues in 1999 with the sale of distributions. Ten percent each came from programming and consulting services, sale of complete solutions including hardware and software, and miscellaneous related activities.

on to the users, and thus the crucial entry barrier – cost advantage – is rendered ineffective. In all of the market segments mentioned, a second competitor – the Linux distributor – has emerged, changing the existing market structure from a natural monopoly to an oligopoly with a small number of competitors, strong entry barriers for commercial software developers, and a large number of buyers.[14]

Within each market segment for server operating systems, the former monopolist now competes with the Linux distributors and 'self-producers', and the latter two bear significantly lower costs.[15] At the same time, the simple fact that some proprietary operating system developers manage to sell their products at higher prices than that of a Linux distribution indicates that the goods offered are to some extent heterogeneous. Although proprietary server operating systems and Linux are substitutes, customers have different preferences with regard to the bundle of product characteristics offered by the software. As Bessen (2004) has shown, a complex software possesses a huge number of product characteristics which, of course, influence the purchase decision. While some product characteristics have a direct benefit/loss for the user (e.g. software features included or not included), other product characteristics might lead to additional costs if the software is introduced (e.g. transaction costs through network effects, ease of use and installation, reliability of the software, available programs for the server operating system).

I use a Launhart–Hotelling model[16] to describe competition within one of these market segments upon entry by Linux firms. The Linux firms emerge due to the possibility of free entry into the market and the costless availability of Linux. They operate under conditions of perfect competition in relation to each other, i.e. zero profits, with prices equal to marginal costs. Assuming homogeneity of the Linux firms, the model can be simplified by postulating a single representative 'Linux firm'. Thus, the market segment is characterized by a duopoly containing one incumbent – the former monopolist – and one entrant, the Linux firm. The incumbent faces development costs associated with its operating system, but the Linux firm has no development costs, since these are carried entirely by the volunteer programmers. The competitors offer heterogeneous products, and therefore prices can differ to some extent without the lowest price supplier taking the whole market. Nevertheless, since the products are substitutes for each other, the sales volumes are functions not only of their own prices, but also of the price of the competing product.[17] The following standard demand functions are assumed:

$$y_1(p_1, p_2) = \gamma_1 - \alpha_2 p_1 + \alpha_1(p_2 - p_1), \tag{1}$$

$$y_2(p_1, p_2) = \gamma_2 - \beta_2 p_2 + \beta_1(p_1 - p_2), \tag{2}$$

where y_1, y_2 and p_1, p_2 represent demand for and prices of the incumbent and the entrant, respectively; α_i, β_i are the marginal changes of demand with respect to prices. Furthermore, α_1 and β_1 show how strongly the demand changes if one firm's price differs from the price of its competitor. Thus, α_1 and β_1 express the degree of heterogeneity of the two

[14] cf. Market structure of Stackelberg (1934).

[15] Self-producers do not appear explicitly as competitors in the market, but price increases by commercial suppliers lead to an increasing number of self-producers and thus to shrinking markets. Collusion is therefore only possible within a limited range.

[16] cf. Launhardt (1885) and Hotelling (1929).

[17] cf. Tirole (1988) (Chapter 7).

products. With $\alpha_1 = 0$ and $\beta_1 = 0$, the products would be offered in completely separate markets. On the other hand, with increasing values of α_1 and β_1, the products become more and more homogeneous. Demand for a product is increasing in the price of the competitor's product and decreasing in its own price.[18] Each supplier is able to sell some of its product even if the competitor gives its product away for free, e.g. for the incumbent $y_1 = \gamma_1 - (\alpha_1 + \alpha_2)p_1 > 0$ for some $p_1 > 0$ and $p_2 = 0$; furthermore, $\alpha_1 \neq \beta_1$ is due to the fact that y_1 and y_2 represent only the *commercial* demand. Linux 'self-production' is not included. Therefore, the total market size $y_1 + y_2$ varies with price changes. One supplier is able to attract the entire market only if the competitor sets a prohibitive price $\hat{p}$. For example, $y_1 = 0$ at $\hat{p}_1 = (\gamma_1 + \alpha_1 p_2)/(\alpha_1 + \alpha_2)$. Note that the prohibitive price varies with the price of the competing product.

Profits $\pi_i = p_i \cdot y_i(p_i, p_j) - C_i(y_i(p_i, p_j))$ differ in that the costs of the incumbent (C_1) include development costs as fixed costs F_1. Furthermore, we assume constant marginal costs v_i as an approximation of the software duplication process.[19] Thus,

$$C_1 = F_1 + v_1 \cdot y_1(p_1, p_2) \quad \text{and} \quad C_2 = v_2 \cdot y_2(p_1, p_2).$$

Taking the price of the competing product as given, the incumbent maximizes profits by pricing its product such that $\partial\pi_1/\partial p_1 = 0$. This yields the reaction function:

$$p_1 = \frac{\alpha_1}{2(\alpha_1 + \alpha_2)} \cdot p_2 + \frac{\gamma_1}{2(\alpha_1 + \alpha_2)} + \frac{v_1}{2}. \tag{3}$$

The price set by the incumbent depends positively on the price of the entrant, the marginal costs and γ_1, but negatively on product heterogeneity (α_1)[20] and the sensitivity of the incumbent's demand to its own price (α_2). The Linux firm, on the other hand, sets its price equal to its marginal cost, for the reasons described above. The reaction function of the incumbent and the marginal costs of the entrant jointly determine the equilibrium (p_1^E, p_2^E).

As fixed costs are not considered in short-term profit maximization, the difference between the incumbent and the Linux firm does not enter into the short-run model. The long-run profitability of the incumbent requires that the incumbent's price covers the total average costs so that the enterprise does not make losses. Whether or not the incumbent will be able to obtain a price above average costs depends ultimately on the customers' preferences. For $\pi_1 \geq 0$, it is required that $(p_1 - v_1)(\gamma_1 + \alpha_1 v_2 - (\alpha_1 + \alpha_2)p_1) \geq F_1$. Let $(\gamma_1 + \alpha_1 v_2) = \Omega$ and $v_1(\gamma_1 + \alpha_1 v_2) = \Phi$, then profitability requires:

$$\Omega \cdot p_1 \geq F_1 + (\alpha_1 + \alpha_2)(p_1^2 - p_1 v_1) + \Phi. \tag{4}$$

A useful way to see what this inequality implies is to look at Fig. 1, which shows the behavior and interrelation of pricing and profits. The left-hand side of Inequality 4 can be represented by a straight line with positive slope emerging from the origin. The right-hand side of Inequality 4 represents a U-shaped curve that is symmetrical to the vertical line $p_1 = \frac{v_1}{2}$ which determines the positive minimum $F_1 - \frac{1}{4}v_1^2(\alpha_1 + \alpha_2) + v_1(v_2\alpha_1 + \gamma_1)$. It intercepts the ordinate at point $F_1 + \Phi$.

[18] It is assumed that $y_i, \alpha_i, \beta_i, \gamma_i > 0$.

[19] The software duplication process consists mainly of pressing CDs, printing manuals and packaging the two. cf. Houghton (1992) or Hetze (1999).

[20] $\frac{\partial p_1}{\partial \alpha_1} < 0$ is true for the relevant case $p_1 \geq v_1 \geq v_2$.

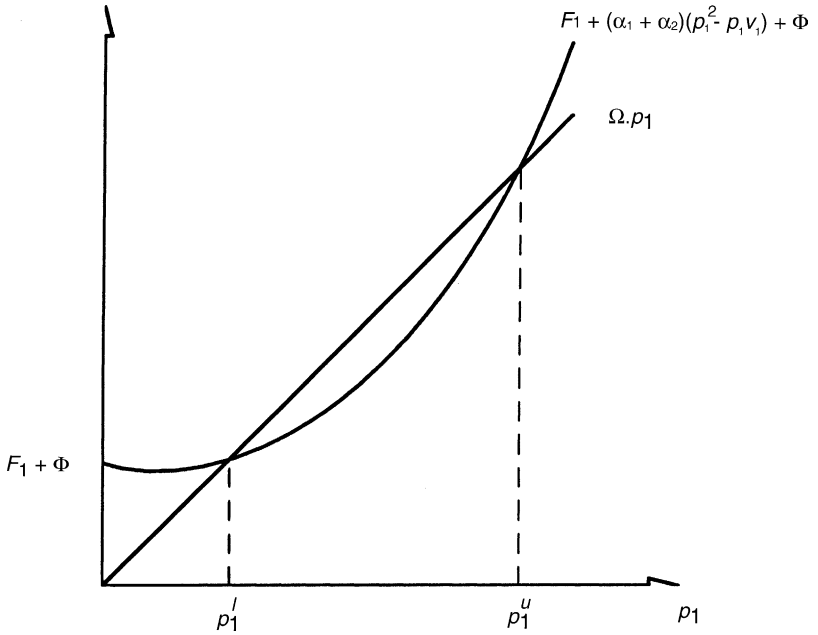

Fig. 1. Profitable price area for the incumbent

The incumbent makes profits only as long as the price lies between p_1^l and p_1^u. With increasing homogeneity between the products (larger α_1), the slope of the straight line and the slopes of both branches of the quadratic function become steeper. However, it can be shown that the profitable price area p_1^l to p_1^u decreases in α_1 and eventually vanishes completely (see, Appendix A for proof).[21] Thus, price-setting strategies and profitability depend on the product heterogeneity reflected by the parameters α_1 and β_1. Heterogeneity enables the incumbent to stay in the market by charging prices higher than the Linux firm. Accordingly, the incumbent's survival depends on successful maintenance of the product's heterogeneity. This, of course, is influenced by the technological development of the two competing products.

4. Real-world behavior as a model 'test'

Under normal circumstances, we would attempt to estimate the parameters of the model for the different market segments using data on relative prices and quantities of Linux versus incumbent firms. As noted in Section 2, however, due to the free distribution of Linux, reliable data on market shares, prices and use of Linux are not available. Therefore, an assessment of the model's predictions can only be carried out through the observation of

[21] Another way of looking at this result is to plug the profit-maximizing price into the profit function and calculate the corresponding α_1 for $\pi_1 = 0$. The resulting value for the zero profit α_1 is of course identical to the α^* derived in Appendix A.

Table 4
Linux supported by OS producers

Manufacturer	Proprietary OS	Support of Linux
Apple	Mac OS X Server V.10.3	No
Compaq	ULTRIX (formerly DEC)	Yes
	OpenVMS OS	Yes
Hewlett Packard	HP-UX11i V.1	Yes
IBM	AIX 5L V.5.2	Yes
Microsoft	Windows Server 2003	No
Novell	NetWare 6.5	Yes
Siemens	Reliant UNIX	Yes
SGI (Silicon Graphics)	IRIX 6.5	Yes
Sun	Solaris 9 OS	Yes

Source: Information on websites of the enterprises mentioned.

the real-world behavior of the participating enterprises. Again, the market for server operating systems is well suited to this task.

The majority of incumbents produce a proprietary variant of UNIX (cf. Table 4) and are therefore very similar to Linux which is a UNIX variant itself.[22] Furthermore, the porting of business application software by commercial software enterprises from UNIX to Linux has further decreased the heterogeneity. Thus, the heterogeneity between Linux and those incumbents' operating systems is low and the price pressure is therefore high. As the model shows, with decreasing heterogeneity, there can come a point at which an incumbent is no longer able to cover its development costs, and thus begins to make losses on the development of its operating system.

Although not obvious, there is a link between the low heterogeneity of proprietary UNIX variants to Linux and the involvement of these incumbents in supporting Linux. All of these enterprises also produce servers. The reliability of their server systems depends heavily on the smooth functioning of the operating system used. Thus, for their sales and service businesses, the operating system is a critical component.

Given the low heterogeneity, there are two reasons why a switch to Linux is rational for the commercial enterprises mentioned. First, due both to the participation of volunteer programmers and to the modifications made available for free by other commercial enterprises supporting Linux, the further development of Linux is cheaper than the further development of the incumbent's own operating system.[23] Second, as Linux is freely available and can be freely adapted to one's own needs, using it does not lead to a dependency on another enterprise in this business-critical component.

Weak heterogeneity and the availability of a cheaper alternative leads commercial enterprises to reconsider developing their own operating systems further. Supporting Linux is the only practical way to switch to another operating system in the long-run, because customers' IT strategies are based on long-term planning and the migration of old systems is often very costly or sometimes impossible. Thus, to keep old customers,

[22] For example same commands, network protocols, file systems, etc.
[23] cf. CNET News.com (2003).

the development of the proprietary operating systems cannot be stopped in the short-term. Therefore, if the firm produces servers, low heterogeneity first leads the firm to support Linux. As Table 4 shows, *all* manufacturers of UNIX variants were already supporting Linux by 2001.[24]

Furthermore, in an interview with the magazine CNET News.com, Steve Mills, Senior Vice President and Group Executive Software Group announced for the first time that Linux will replace AIX. He stated further that Linux is the logical successor of AIX but the replacement would not happen overnight.[25] As one reason for the switch to Linux, Mills mentioned the low costs of further development. Furthermore, announcements by Novell, upon acquiring the Linux distributor SuSE, suggest that NetWare could become the first server operating system terminated in favor of Linux.[26]

In market segments where the incumbent's operating system is not a UNIX variant, the situation is entirely different. Apple's and Microsoft's server operating systems differ from Linux on a number of important points. To mention only a few: WindowsNT/2000/Server2003 and Mac OS Server operating systems are based on a graphical user surface, both operating systems are strongly interlaced with application software, and both operating systems use proprietary file systems. Thus, product heterogeneity is obviously higher than in the case of the proprietary UNIX variants.

If product heterogeneity still permits a price above average costs, it would be rational for these enterprises to proceed with the development of their operating system, while still maintaining or even increasing product heterogeneity. The behavior of Apple and Microsoft points in this direction. First, both enterprises still sell their server operating systems at a higher price than that of a Linux distribution.[27] Second, both enterprises further develop their operating systems while at the same time increasing the heterogeneity of their product relative to Linux. For example, both enterprises continue to add software components, additional functions, proprietary standards, and to interlace application software with their operating systems.[28] Third, both refuse to support Linux in any way. For example, Microsoft will not port MS Office to Linux, thus foregoing potential profits and, even worse, risking that competitors like StarOffice, Koffice or Wordperfect become the dominant office application software on Linux.

The continuing development of the commercial suppliers' operating system software, the strong focus on extending the range of product functions and the refusal to support Linux in any way can be interpreted as attempts to maintain and increase the heterogeneity of their product relative to Linux. Any support for Linux whatsoever would decrease the heterogeneity between Apple's and Microsoft's operating systems and Linux, resulting in increased price pressure with a danger of losing the ability to cover the development costs.

[24] One of the first supporting enterprises was IBM, the last was HP starting in June 2001.
[25] cf. CNET News.com (2003).
[26] See [http://www.novel.com].
[27] The price for Windows Server2003 with a five-client licence is US$ 999 – (June 2004) and for a Mac OS X Server V.10.3 licence, US$ 999 – (June 2004).
[28] The most famous example of this is the integration of Microsoft's web browser, MS Internet Explorer, into Windows; cf. Waldman and Jensen (2000), p. 543.

5. Conclusions

The production of complex software entails substantial development costs, making software production a fixed-cost business resulting in a natural monopoly. With the emergence of reliable open source software, formerly non-contestable markets have turned into oligopolies. The incumbents are confronted with entrants who have significantly lower costs because their development costs are carried by volunteer programmers. A simple Launhart–Hotelling model has been used to show that the long-run survival of the incumbent depends ultimately on the heterogeneity between the incumbent's and the entrant's software product. If the heterogeneity falls below a certain level, the incumbent will no longer be able to cover its fixed (development) costs, and will thus exit the market.

The model's implications provide some useful insights into the differing behavior of producers of server operating systems. While some support Linux, others do not. Due to the low heterogeneity of their products relative to Linux, enterprises producing a UNIX variant face severe price pressure, making further development risky in terms of being able to cover their development costs. Supporting Linux, which further decreases their own product's heterogeneity vis-à-vis Linux, is only a first step towards the replacement of the incumbent's proprietary operating system altogether. Enterprises producing a non-UNIX server operating system, like Microsoft and Apple, benefit from higher product heterogeneity. They can still charge much higher prices for their server operating systems and are therefore still able to cover their development costs. Refusal to support Linux is rational for them, as it maintains the heterogeneity of their products relative to Linux. A decrease of product heterogeneity would entail the risk of losses in the further development of their proprietary operating system.

Clearly, further research is needed, first towards modelling the dynamic process of diffusion and technological development of Linux and thus the changing heterogeneity to other operating systems, and second towards modelling customers' preferences. Both areas of research can help to predict the future development of the different market segments, including the destiny of Microsoft, the last major opponent to Linux.

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Appendix A

Proof that the incumbent's profitable price area p_1^l to p_1^u decreases with an increase of α_1 and eventually vanishes completely.

From the main text, Inequality 4, define $s = \Omega p_1$ and $q = F_1 + (\alpha_1 + \alpha_2)(p_1^2 - p_1 v_1) + \Phi$. Intersections of s and q are given by:

$$p_1^l = \frac{a - \sqrt{b}}{c}$$

and

$$p_1^u = \frac{a + \sqrt{b}}{c},$$

where $a = v_2\alpha_1 + v_1(\alpha_1 + \alpha_2) + \gamma_1$, $b = -4F_1(\alpha_1 + \alpha_2) + (v_2\alpha_1 - v_1(\alpha_1 + \alpha_2) + \gamma_1)^2$, and $c = 2(\alpha_1 + \alpha_2)$.

Define $\alpha^* = \frac{2F_1 + 2\sqrt{F_1}\sqrt{F_1 - (v_1 - v_2)(v_2\alpha_2 - \gamma_1)} - (v_1 - v_2)(v_1\alpha_2 - \gamma_1)}{(v_1 - v_2)^2}$. Then, $\lim_{\alpha \mapsto \alpha^*} b = 0$, and hence p_1^l and p_1^u collapse into one point. Notice that $p_1^l \lim_{\alpha \mapsto 0} = \frac{v_1\alpha_2 + \gamma_1 - \sqrt{-4F_1\alpha_2 + (\gamma_1 - v_1\alpha_2)^2}}{2\alpha_2} < \frac{v_1\alpha_2 + \gamma_1 + \sqrt{-4F_1\alpha_2 + (\gamma_1 - v_1\alpha_2)^2}}{2\alpha_2} = p_1^u \lim_{\alpha \mapsto 0}$. Since q is monotone increasing in the relevant parameter range, and since p_1^l and p_1^u are monotone in α_1 it remains to show that $\frac{\partial q}{\partial p_1}|_{p_1 = p_1^l} < \frac{\partial q}{\partial p_1}|_{p_1 = p_1^u}$. Evaluating $\frac{\partial q}{\partial p_1} = (2p_1 - v_1)(\alpha_1 + \alpha_2)$ for p_1^l to p_1^u this condition becomes $-b < +b$ which is always true. □

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