Diffusion and Competition of PC Operating Systems*

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Abstract

In the last few decades, Microsoft has succeeded in maintaining a pretty stable market share of around 90 per cent in the PC operating systems market. While the commonly used threshold for a near-monopoly is 70 per cent, we suggest that a closer look has to be taken in this case at the way overall market share can be decomposed. By examining a four-year panel covering three generations of mainstream Microsoft systems, we find that while Microsoft's overall market share has been remarkably constant, firms show an increasing tendency to use additional operating systems on a small scale, which indicates a growing fragmentation of the PC operating systems market through niche products.

We then study the diffusion of several operating systems and identify three categories of OS, the 'loser' systems, 'increasing returns' systems, and 'decreasing returns' systems. We claim that the decreasing returns systems are natural niche products that will settle on a natural percentage of usage, while increasing returns OS tend to standardize throughout the entire firm. 'Loser' OS are mainly operating

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systems that are in the process of being replaced or phased out. In addition, we also find that new generations of Microsoft products are strong complements, while some of the older competitors of Windows 3 seem to provide much of the population that switched to the Windows standard. *JEL: L86, L12. Keywords: Operating Systems, Diffusion, Intra-firm Diffusion.*

1 Introduction

Operating systems are a typical example of a network good; the more PCs are equipped with a certain OS, the more attractive it becomes to essentially all parties involved: End-users will find their skills of working on that particular operating system more transferable, IT-specialist will find that their experiences in dealing with problems concerning the OS are more valuable, software programmers will expect a higher potential market for their programmes if they are written to comply with the OS, and manufacturers of microprocessors will find it more attractive to cooperate with the OS producers in order to achieve maximum synergies between OS and processor. This has long been shown to lead to a particularly beneficial position for the final participant in the industry; the copyright owner of the operating system itself. Network effect of the sort described above can lead to extreme market structures approximating a monopoly, and through the installed base of users of the dominant OS, new, possibly superior operating systems will face significant and sometimes even insurmountable barriers to entry.

Studying the dominance of a single product, however, seems unrealistic in the face of the rapid introduction of new products by the market leader. The "Microsoft standard", as it has been termed, consists of an entire family of operating system that are being used concurrently, sequentially, competingly and complementary. Yet, the persistence of Microsoft's dominance has exceeded that of many other (near-)monopolies in recent history. In this paper, we will examine this puzzle in more detail and characterize the patterns of intra-firm standardization that have arisen in the operating systems industry in recent years. We also discuss the stylized fact that there seems to be a rather stable "fringe" of niche operating systems that seems to be able to survive. We show that even though the overall size or thickness of the fringe has remained rather constant over time, the consistency of the fringe has changed considerably in that time period.

This study is part of the attempt to answer the larger question: Are firms' incentives to achieve firmwide compatibility[1] by using a single operating system dominated by other factors, and if so, what are these factors?

We can think of two kinds of incentives that may counteract the forces for standardization: Firstly, using multiple standards could be a dynamic phenomenon. New versions of established OS are being introduced every few years, and with uncertainty about future generations' timespan and quality, a firm might be unwilling and unable to exert a full switch to the latest version of their current OS or even run several OS concurrently in order to be able to catch a bandwagon building for a new technology. Secondly, however, using multiple standards could also be a static phenomenon, meaning that there is an equilibrium with more than one OS in use and may therefore exist over several years and OS generations. Here, we would expect some operating systems to hold a relatively constant share of the market simply because they are the best systems for this particular subset of firms. The first line of argument is the focus of this paper. We answer the second question in more detail in Kretschmer [17].

We study the evolution of different operating systems over time is studied in detail using a four-year panel. In particular, we study the following questions:

a) Are firms using one or multiple operating systems on their computers? Is the tendency to use one or more OS stable or changing over time?

b) Does the dominance of mainstream Microsoft products on aggregate increase over time? How persistent is Microsoft as the industry standard and how persistence is use of individual operating systems.

c) What does the diffusion of Windows 3 look like? Which OS are displaced by Win3? Does the diffusion of Win3 display network externalities? Is the incumbent dominant system, MS-DOS, displaced by Windows, and what other factors accelerate the phasing out of MS-DOS?

d) What shape does the diffusion/dynamic behaviour of all the major operating systems take? Do all the OS display network effects, or do some of them have decreasing returns to adoption?

These four questions allow us to get a clear picture of the dynamic phenomena going on in a market with frequent product introduction and a dominant firm striving to keep entrants out or at least small. We find that dominance of mainstream products does not increase on the whole, and that

[1] Arising, e.g. through the existence of significant network effects.

there is a relatively stable fringe of niche products surviving in the market. What is notable, however, is that firms that have initially used just the main Microsoft family and have started using additional operating systems are increasingly turning to Microsoft niche products, thus increasing overall dominance of Microsoft, if not the mainstream Microsoft family.

Related Literature

The empirical literature on markets displaying network externalities has been increasing vastly in the past years. Tests for network externalities include computer spreadsheets [6],[11], Yellow Pages [18], CD players and disks [12], DVD players [8], and ATM machines [19], among others. Also, the competition between the IBM-Microsoft-Intel standard and Apple/Macintosh has been analyzed in Greenstein and Salant [14]. The effects of the intensity of competition between the two systems on diffusion speed has been documented by Koski [15]. All these studies show, roughly speaking, that a larger installed base will manifest itself either in a higher price (spreadsheets, Yellow Pages), the availability of complementary goods (CDs) or the speed of diffusion (ATM machines, PCs). What is common to all the results, however, is that a larger installed base has a positive influence on the value of the technology. Expanding on this argument, a standardized market seems possible, if not likely, thus confirming the theoretical results first formalized by Arthur [2] and Arthur et al. [1] that a market exhibiting significant unbounded increasing returns will eventually settle on one industry standard. However, empirical studies explicitly covering multiple generations of the dominant technology do not yet exist.

There have been a number of theoretical papers studying the transition from an old dominant technology to a new one and whether dominance in earlier generations can be "migrated" to the new technology. In particular, phenomena of planned obsolescence and product preannouncements have been analyzed theoretically. Choi [7] studies the effects of planned obsolescence on future market structure and technological progress and argues that planned obsolescence may actually work against a monopolist, since consumers knowing that a product will be obsolescent before long will have a lower willingness to pay for the good or delay adoption of the product. This might be an important reason for firms not to upgrade fully to a new generation of their current operating system, in addition to uncertainty about the new product's quality. Vaporware, on the other hand, can be used as

a competitive instrument to prevent buildup of a competing installed base, as shown by Dranove and Gandal [8] on the example of DVD vs. DivX, and analyzed theoretically by Farrell and Saloner [9] and Kretschmer [16], who show that adopters' incentives to invest decrease with the knowledge of another product appearing in the future. So, while letting producers know about a future technology might be beneficial for a firm, it might also be harmful by cannibalizing current sales.

Another strand of research relevant to this paper is the literature on intra-firm diffusion, since our data gives us the opportunity to analyze the gradual replacement of an old technology with network effects by a new generation.[2] Papers that specifically concern themselves with diffusion within a firm are relatively scarce. Stoneman [20] develops an equilibrium model that takes into account the expected profitability of a new technology and confirms that within a firm, a more profitable technology will be adopted faster. Battisti [3] expands on this model and shows that higher uncertainty and lower adoption cost will speed up intra-firm diffusion, while diffusion appears to be independent of market structure. In an empirical study, Stoneman and Battisti [21] find significant rank effects (i.e. firms can be ranked in order of their expected profitability of adopting a new technology), while they do not detect an impact of market concentration measures on diffusion speed. The scarce evidence, however, at least seems to warrant accepting the hypothesis that the diffusion of new technologies within a firm depends mainly on internal factors rather than competitive pressures. Still missing in the literature, however, are studies on the effect of competing new technologies and the effect of market structure in the market for the new technology rather than the adopting firms on intra firm diffusion.

The paper is structured as follows. Some quantitative features of the OS industry are established and discussed in Section 2. The process of replacing old generations of OS is highlighted and analyzed in Section 3. A dynamic model of OS diffusion is proposed and estimated in Section 4. We conclude in Section 5.

2 Some Data on the OS Market

Data Description

[2] A recent survey of research on diffusion within markets (i.e. inter-firm diffusion) is given in Geroski [13].

Our data is a four-year panel covering the years 1994-97. It is part of periodic telephone surveys conducted by ZD Market Intelligence (now Harte-Hanks Market Research). The data was provided to us by Luke Spikes and Matthew Shannon.

In our panel, firms report the percentage usage of several operating systems and are assigned an identifier that allows us to track their usage of specific OS over time. The total number of firms surveyed giving complete information (i.e. reporting 100% of their OS usage) varies from 2472 (in 1994) to 4755 (in 1996). A balanced panel of firms with satisfactory data throughout the four years leaves 1686 firms. The firms qualifying for the balanced panel do not seem to be different from the rest in the characteristics available to us. In particular, the average usages of the operating systems in the sample do not differ greatly in the balanced and unbalanced panel, as Table 1 shows.

Table 1
Average OS usage over time[a]

Year	94		95		96		97	
Sample	bal.	unbal.	bal.	unbal.	bal.	unbal.	bal.	unbal.
OBS	1686	2472	1686	4572	1686	4755	1686	4726
MS_DOS	.824	.82	.359	.369	.252	.258	.16	.159
WIN 3.x	.068	.068	.608	.599	.692	.685	.656	.638
WIN 95	.0	.0	.0	.0	.007	.008	.081	.096
MS_TOT	**.892**	**.888**	**.967**	**.968**	**.951**	**.951**	**.897**	**.893**
WIN NT	.017	.016	.001	.002	.006	.007	.024	.028
SCO UNIX	.016	.017	.002	.003	.003	.003	.003	.002
WINWKS	.0	.0	.0	.0	.011	.011	.045	.049
OS/2	.061	.063	.021	.016	.022	.016	.021	.017
MAC	.0	.0	.005	.008	.005	.008	.005	.008
OTHER	.014	.014	.004	.005	.002	.004	.005	.004

[a]Figures report the average of the figures given by all firms each year about what percentage of PCs in their establishment are running on a certain operating system.

Features of the Data

In what follows, we will discuss a number of features of the data. We will refer to the first dataset as the panel and the second dataset as the cross-section.

Table 1 summarizes the average market shares across firms of the OS in our sample for the unbalanced and balanced panels, respectively. We clas-

sify the operating systems up into mainstream Microsoft operating systems and a "fringe". The mainstream OS include MS-DOS, Windows 3.0 and subsequent upgrades, and Windows 95, since they were specifically designed and launched to capture the mass market of OS users.[3] Windows NT, even though it is also a Microsoft product, had been launched in order to establish a foothold in the high-end market and therefore does not count as a mainstream system. While conventional Windows and MS-DOS have been developed further in order to capture an even wider population of users, their primary appeal was always to the mass market user.

We can see from the Table 1 and Figure 1 that the size of the fringe across our sample has remained remarkably constant, whereas the variations in the market shares of the dominant systems have varied dramatically in the time period. MS-DOS has shrunk in market share from 82% to just over 10%, while Microsoft Windows 3.x had 6.8% at the beginning of the sample, reached a peak at 68.5% in 1996, and had already declined to 57% by 1998. On the other hand, Windows95 was still in the ascending stage since its first measurement in 1996 of approximately 1%. By 1998, on average 23.7% of PCs in the firms in the sample were running on Windows 95. It is interesting to contrast this with the overall Microsoft mainstream marketshare, which varied less than ten percentage points in the course of the five years.

We will now examine whether the fluctuations in the market shares of DOS, Windows 3, and Windows 95 we saw in the aggregate data also occur on a firm level. In particular, we want to see whether firms upgrade their PCs to a new generation of operating systems in one go, or if firms adopt a more gradual displacement path. Table 2a gives a count of the occurrences by year of firms using combinations of the dominant systems, DOS, Windows 3, and Windows 95. In Table 2b, we impose a threshold usage of 25% (chosen arbitrarily) of PCs within a firm to determine whether simultaneous usage is a case of using multiple systems at similar intensity, or using a main system

[3]Bill Gates' famous quote is: "My vision is a computer on every desk and in every home, all running Microsoft software."

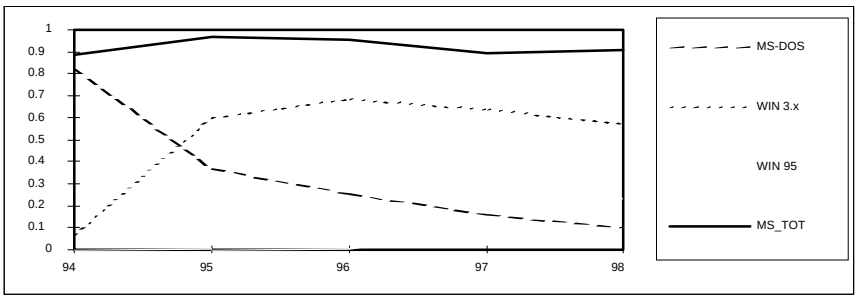

Figure 1: Market Share Fluctuations of Mainstream MS OS.

and others only marginally.

Table 2a
Count of combinations of mainstream OS

Year	94	95	96	97
DOS	1406	108	79	68
DOS+WIN3	32	1119	853	505
WIN3	103	446	653	613
DOS+WIN3+WIN95	0	0	29	98
DOS+WIN95	0	0	2	13
WIN3+WIN95	0	0	30	243
WIN95	0	0	8	81
TOTAL	1541	1673	1654	1621
% single OS/total[a]	97.92%	33.11%	44.74%	47.01%

Table 2b
Count of combinations of mainstream OS, threshold > 25%

Year	94	95	96	97
DOS	1392	102	74	58
DOS+WIN3	11	473	346	211
WIN3	102	443	647	600
DOS+WIN3+WIN95	0	0	1	3
DOS+WIN95	0	0	1	3
WIN3+WIN95	0	0	4	57
WIN95	0	0	5	54
TOTAL	1505	1018	1078	986
% single OS/total[a]	99.27%	53.54%	67.35%	72.21%

[a]This gives the percentage of firms using a single mainstream OS as a proportion of all firms using exclusively mainstream OS. 50% means that half the firms that use exclusively MS mainstream OS are using just a single one, while the other half uses a combination of them.

With the exception of 1994, where the overwhelming majority was using just one of the mainstream systems, there is a significant fraction (between $33 - 47\%$) of firms who use multiple generations of the dominant OS family. By definition, the proportion of users who use multiple OS to a similar extent is smaller (since the cases with exclusive use of a single OS are captured in both tables, while firms using almost exclusively one OS would not enter the latter Table 2b), but even imposing a threshold value of 25 percent of the PCs in the firm leaves between about a quarter and one half of firms using multiple systems between 1995 and 1997. Therefore, in addition to the fact that fringe operating systems are used widely on a fraction of a firm's PCs, a significant number of firms phase out their old systems only gradually, thereby creating a situation where subsequent generations are being used simultaneously within the firm. It is quite likely that even between different generations of operating system used simultaneously some form of splitting of tasks takes place. New systems introduce new functionality, which provides for a natural split, but since the processing requirements increase with every new generation, one can expect that lower-end machines that are being used for simpler tasks will remain equipped with the older system, while high-end machines will perform the more demanding tasks using the more recent OS. This "vertical division of tasks", however, is unlikely to be the cause

for partial upgrading of operating systems, but rather the effect, since more recent generations will be able to perform all tasks the older version could.

When a new generation of the Microsoft family is released, firms seem to take their time installing it on the majority of their PCs. Therefore, overwhelming dominance of a single product within the firm seems much more infrequent than aggregate market share figures suggest. This then raises an important question: Does Microsoft's dominance persist over several generations of operating systems? While on the aggregate level the question can quite easily answered in the affirmative, we will examine the question on a micro-level, i.e. within firms. We find that even though aggregate dominance seems more or less unaffected by rapid introduction of new generations, firms increasingly tend to use other products on a small scale, which may be indicative of firms' uncertainty about the new generation's quality or lifespan.

3 The Dynamics of Operating Systems Usage

Even though Windows (and in earlier years Microsoft's DOS) commands a large share of the market, no one Microsoft system is used exclusively in any one year. The rapid introduction of new and improved versions of Windows means that very few firms will be able (and possibly not willing either) to upgrade their entire population of PCs to a new OS. There are numerous reasons why this should not happen. Firstly, financial limitations may make it impossible to replace operating systems on all PCs at one point in time. Secondly, hard-and software upgrading might be synchronized so that an introduction of a new operating system immediately after its release might not be the cost-minimizing option taking into account hard- and software costs. Thirdly, firms may be uncertain about the quality of the new OS, so firms might minimize their risk by installing it on a limited number of PCs only. We will examine the behaviour of firms using a panel of UK firms on the usage of operating systems.

Since the panel does not include information on firm descriptives, it is not possible to build a dynamic model of the determinants of intra-firm adoption on the basis of exogeneous variables. However, the actual behaviour of firms regarding their degree of standardization on an operating system and the evolution of certain groups of firms over time will provide the basis for our conclusions about the aggregate behaviour of our sample.

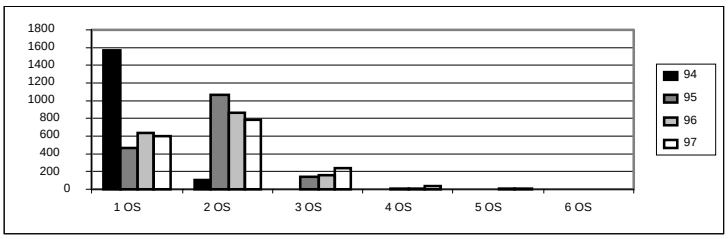

Figure 2: Evolution of number of OS used.

3.1 The evolution of the number of OS used

The following two histograms plot the number of firms that use 1, 2, etc. operating systems in a particular year. We can see that there seems to be a tendency to use multiple operating systems, especially if 1994 is taken as the base year, since there more than 90 percent of firms use only one operating system, while in later years the most frequent case is simultaneous usage of two operating systems.

By constructing a Markov matrix with the transition probabilities from using n OS to using m OS, we can further illustrate the tendency to use more OS as time progresses.

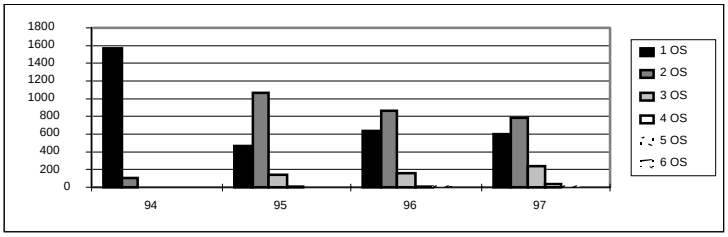

Figure 3: Evolution of Number of OS used, by Year.

Table 3
Markov Matrix for Transition between Numbers of OS used[a]

# OS in t	# OS in $t+1$: 1	2	3	4	5	6
1	.461	.45	.077	.009	.003	.0
2	.205	.7	.077	.012	.004	.001
3	.162	.248	.556	.033	.0	.0
4	.061	.182	.273	.455	.03	.0
5	.0	.071	.071	.214	.643	.0
6	.0	1	.0	.0	.0	.0

[a]The matrix is constructed using the 4-year panel. The transition probabilities are calculated as $prob\left(m_{t+1}\,|n_t\right) = \frac{\left(m_{t+1}|n_t\right)}{n_t}$

Each percentage is the probability that a firm using n OS in t will use m OS in $t+1$. For example, almost half (45%) of users of a single operating system in t progress to using two in the following year, 7.7% of users of a single OS use three OS, .9% use four, and .3% go from using a single operating system to using five. By iteratedly applying this transition matrix for a set of different initial conditions (i.e. distributions of firms using 1, 2, etc. OS),

we can tentatively come up with a back-of-the-envelope estimate of the long-term shares of firms using 1, 2, etc. operating systems. In Table 4 we give the percentages of firms using n operating systems in 94-97, and finally the estimated long-run shares in the final column.

Table 4
Actual shares of # OS by year and long-term estimate[a]

		94	95	96	97	$t = \infty$
	1	.933	.273	.38	.355	.257
	2	.063	.631	.512	.466	.542
# OS	3	.004	.084	.091	.145	.159
	4	.0	.008	.012	.026	.03
	5	.0	.004	.005	.007	.011
	6	.0	.0	.001	.001	.001

[a]The long-term estimates are obtained by inserting a random distribution of firms using n OS and applying the transition probabilities repeatedly until the fluctuations in shares do not exceed .1 percent. This typically occurs after 30-50 repetitions. The estimated share of firms s_m^{t+1} running m OS at time $t+1$ is
$s_m = \sum s_n^t prob\,(\#OS^{t+1} = m\,|\#OS^t = n\,)$,
i.e. the expected proportion of firms making the transition from n to m OS, weighted by the previous share of firms using n OS.

Without trying to read too much into these calculations, this result seems to confirm the evidence that firms tend to use more operating systems than at the beginning of the sample. In the long run, the majority of firms are expected to use two operating systems, and roughly one firm in five will use even more than two OS.

Additional evidence for the trend towards the usage of additional OS on a small scale within the firm can be found in Table 5. We track the number if firms using either exclusively mainstream Microsoft products (i.e., $\sum MS = 100\%$), predominantly Microsoft products ($\sum MS > 50\%, < 100\%$), or not

as a main system ($\sum MS < 50\%$).

Table 5
Evolution of standardization and dominant use of MS

Year	94	95	96	97
$\sum MS = 100\%$	1457	1411	1375	1203
$\sum MS > 50\%, < 100\%$	37	233	238	319
$MS < 50\%$	192	42	73	164

It is striking that the number of firms using exclusively Microsoft OS is constantly declining in the panel, while the number of firms that use Microsoft systems as main, but not exclusive system increases approximately eightfold in the time span of the panel: By 1997, over one fifth ($\frac{319}{1203+319} = .21$) of firms using mainly Microsoft OS are not exclusive users, which compares to approximately two percent in 1994. That is, while in 1994 "to use Microsoft OS as a main system" was almost synonymous with "to use *exclusively* MS OS", it is becoming increasingly more common to use other operating systems on a small fraction of their PCs. On the other hand, overall dominance, i.e. all firms using Microsoft OS on more than half of their PCs, fluctuates around 90 percent. Overall, this clearly is another indication that there is a tendency to usage of additional OS as niche products within a firm.

3.2 Persistence of the Microsoft Standard

The 1994 market leader, MS-DOS, was subject to an immense attrition rate by their consumers in the following years (even if not as dramatic as the second most popular system, IBM OS/2, as will be demonstrated in a later Section). However, this seemingly has not influenced the overall dominance of Microsoft. It is interesting, therefore, to see how high the attrition rate (or its flipside, the persistence) of MS users is across several generations of operating systems. In our panel, three successive generations of mainstream products were on the market simultaneously. It seems intuitive that firms upgrading to a new system anyway might be more likely than firms that are not in the process of upgrading to opt for an additional OS altogether.[4] Therefore, we

[4]It has been shown on the example of word processing and spreadsheet software by Breuhan [5] that switching cost decreases (and the probability of changing brands increases) when a new generation of the incumbent product becomes available.

will examine the persistence of the Microsoft standard across generations in more detail. We use the definitions of "exclusive" and "predominant" MS use from the previous section. Tables 6a and 6b give a summary of the results for exclusive and predominant MS use.

Table 6a
Persistence of Exclusive MS use

Year	94	95	96	97
% of firms $\left(MS^t = 100\%\right)^a$	.864	.837	.816	.714
# of firms $\left(MS^t = 100\%\right)$	1457	1411	1375	1203
% of firms $\left(MS^t = 100\% \right.$ & $\left. MS^{t-1} = 100\%\right)^b$	1457	1227	1144	989
$\left(\frac{MS^t = 100\%}{MS^{t-1} = 100\%}\right)^c$		.842	.933	.865
$\left(\frac{MS^{97} = 100\%}{MS^{94} = 100\%}\right)$				.679

Table 6b
Persistence of Predominant MS use

Year	94	95	96	97
% of firms $\left(MS^t > 50\%\right)^a$	.886	.975	.957	.903
# of firms $\left(MS^t > 50\%\right)$	1494	1644	1613	1522
% of firms $\left(MS^t > 50\% \right.$ & $\left. MS^{t-1} > 50\%\right)^b$	1494	1461	1428	1359
$\left(\frac{MS^t > 50\%}{MS^{t-1} > 50\%}\right)^c$		.978	.977	.952
$\left(\frac{MS^{97} > 50\%}{MS^{94} > 50\%}\right)$				.91

[a] The total percentage of firms using exclusively or predominantly MS OS per year.

[b] The percentage of firms using exclusively or predominantly

[c] The fraction of firms that have used MS OS exclusively or predominantly in 94 still using the same intensity of MS OS.

As becomes evident from comparing Tables 6a and b, the degree of persistence is much higher for predominant than exclusive use of mainstream

Microsoft OS. Even though a part of this observation stems from the construction of our subgroups - since a 1% decline in MS usage implies a "lost" firm in 6a, while the same decline only counts towards the losses in 6b if previous usage was exactly 51% - it still seems remarkable that more than 95% of firms using predominantly mainstream Microsoft products in any given year will continue using mainly Microsoft products in the following year, whereas on average one firm in ten that has been an exclusive user of Microsoft will defect from this policy of exclusive use in any given year, which results in an approximate attrition rate throughout the sample period of 32%. So while it seems quite likely for firms to remain with their standard OS family and upgrade within it, it is quite possible that they will start using other, niche OS in the process, which would explain the large discrepancy between our definitions of standardization (i.e. exclusive and predominant use). A potential explanation could be that the release of new generations is accompanied by uncertainty about the capabilities and quality of the new generation, which could lead a firm to experiment on a limited scale with other OS in order to face smaller costs of switching fully should the new generation mainstream OS prove inadequate or as a niche OS that can perform the tasks the new generation technology falls short of. The general distinction between exclusive and dominant use of mainstream products seems an important one, however.

3.3 Which OS are users turning to from standardization on MS?

Since there appears to be a tendency to move away from using just one (or a combination of) mainstream Microsoft product(s) for all purposes within the firm, we will now try and identify the operating systems that benefit from this tendency, i.e. the systems that are able to gain a small foothold into firms and therefore pass the first entry barrier of getting used in the first place. We will therefore track all firms who have progressed from exclusive DOS, Windows 3, and Windows 95 usage to mixed usage of mainstream Microsoft and other OS.

We capture all instances where $\sum MS^{t-1} = 100\%$, i.e. the firm was using exclusively mainstream Microsoft OS in the previous year, and $\sum MS^{t} < 100\%$, i.e. not all PCs run on one of the three mainstream systems in the current year. There are 574 cases altogether. In Tables 7a-c, we document

the percentage of firms using a specific fringe system in the transition year (i.e., t) and the resulting average share of that fringe system. The final set of statistics gives $\frac{\text{ave use OS}}{\%\text{ using OS}}$, i.e. the average use conditional on using the OS in the first place, as a measure of intensity of use.

Tables 7a-c
Addition of niche OS from exclusive MS OS use

Year	95	96	97
Observations	230	105	239
a) Fraction of firms using specific OS			
% using WinNT	3.91%	36.19%	59.00%
% using WinWK	-	27.62%	33.89%
% using OS/2	74.55%	28.57%	7.95%
% using MAC	15.65%	13.33%	9.62%
% using Unix	10.87%	5.71%	2.51%
b) Sample average use of specific OS			
ave use WinNT	.51%	6.61%	9.18%
ave use WinWK	-	18.12%	23.22%
ave use OS/2	13.60%	3.54%	1.28%
ave use MAC	2.04%	.56%	.57%
ave use Unix	1.32%	2.10%	.63%
c) Average use conditional on $\sum OS > 0$			
ave % if used WinNT	13.04%	18.26%	15.56%
ave % if used WinWK	-	65.60%	68.52%
ave % if used OS/2	18.24%	12.39%	16.10%
ave % if used MAC	13.04%	.04%	.06%
ave % if used Unix	12.14%	36.78%	25.10%

We can see an interesting pattern emerging: While in 1995, IBM's OS/2 was by a long way the preferred choice for firms adding an additional operating system, in later years other Microsoft products, Windows NT and Windows for Workgroups, have been chosen to add to the mainstream MS family. In particular Windows for Workgroups was installed on a rather large fraction of PCs when it was installed ($> 60\%$), indicating that it is indeed

a general-purpose operating system, even if geared towards lower-end users. One could imagine that the new generation of Microsoft operating systems was designed to be interoperable to a larger extent in order to let users take advantage of Microsoft's installed base and the associated network effects while at the same time using an operating systems best geared to its needs. The practice of cross-certifying Windows 95 and Windows NT applications is an example of such a strategy.

Indeed it seems that switching to non-Microsoft operating systems or even using them on a small scale would involve such heavy switching cost that it became increasingly unprofitable to do it and instead choose to diversify within the Microsoft family.

3.4 Which OS is displacing which other one?

We will now examine what the takeup of new operating systems of different groups of firms look like. Here, we are looking at the flipside of adding "fringe OS" to the firm's existing standard; namely the switching from one dominant system to another. In particular, we look at four standards in 1994: DOS, Windows 3.x, OS/2, and other fringe-OS. We track the standardization decision of these four groups over time and report the results in tables 8a-c.

Table 8a-c

Obs	1377	111	96	46
a) 95				
dominant OS in 94	DOS	WIN3	OS/2	NON-MS
DOS	.304	.234	.198	.239
WIN3	.566	.405	.667	.630
WIN95	.0	.0	.0	.0
MS Mix	.121	.171	.104	.065
OS/2	.001	.144	.021	.0
Mixed	.005	.036	.01	.0
Other	.002	.009	.0	.065

b) 96				
dominant OS in 94	DOS	WIN3	OS/2	NON-MS
DOS	.201	.126	.135	.152
WIN3	.682	.595	.698	.630
WIN95	.002	.0	.012	.022
MS Mix	.091	.054	.094	.065
OS/2	.004	.18	.021	.0
Mixed	.010	.036	.01	.043
Other	.001	.009	.021	.087

c) 97				
dominant OS in 94	DOS	WIN3	OS/2	NON-MS
DOS	.114	.054	.063	.130
WIN3	.665	.532	.604	.522
WIN95	.054	.063	.042	.065
MS Mix	.098	.081	.052	.087
OS/2	.004	.189	.021	.0
Mixed	.026	.081	.073	.065
Other	.039	.036	.146	.130

Comparing the DOS-types and the Win3.x-types allows us to make an interesting observation: Dominant usage of Win3.x in the future is lower for the firms that had previously already adopted Windows. Instead, usage of

OS/2 appears to be higher for the Windows-types, which would imply a move away from the Microsoft DOS-Windows standard to another product. In fact, takeup of the Win3.x standard seems to be highest from firms that have been using something else previously. This would indicate that the emergence of Win3.x further attracted previously non-mainstream MS customers to the Microsoft standard, whereas early adopters of Windows seemed to offset the effect by going the other direction, i.e. to use another OS as their standard. The two effects seem to cancel out on aggregate, since the overall dominance of the Microsoft family does not change much over time.

We will now consider only firms who have not been using Windows 3 in 1994, which eliminates 135 observations per year. We choose two subgroups from the sample; DOS-standardized and OS/2-standardized firms (i.e. $>$ 50% DOS or OS/2 use, respectively, in 1994). We can then see whether Windows 3 is adopted more readily by one of the groups and in what way. In Table 9 we therefore report the percentage of firms using Windows 3 at all and the average usage of Windows 3 for each group as a measure of intensity. We also report the shares and intensities of the incumbent system after takeup of Windows 3.

Table 9
Adoption of Windows 3 grouped by incumbent OS

Incumbent OS	Obs		95	96	97
DOS	1363	% using Win3	.947	.899	.809
		ave share Win3	.612	.699	.672
		% using DOS	.737	.586	.42
		ave share DOS	.371	.264	.169
OS/2	96	% using Win3	.969	.927	.792
		ave share Win3	.695	.72	.617
		% using OS/2	.156	.094	.031
		ave share OS/2	.03	.021	.018

We can see that the adoption figures do not seem very different, neither the percentage of firms using Windows 3 nor the intensity of use. However, the market shares of the incumbent operating system do vary considerably when a new OS is introduced. There is a dramatic decline in the ratio of firms still using OS/2, the system they have been running on more than half of their PCs in 1994, after the takeup of Windows. On the other hand, MS-

DOS has a much slower decline in usage shares. The fact that at that time DOS was still required to run Windows does not enter these considerations, since the figures are relative, i.e. percentage figures so that the number of computers running and using DOS to run applications on is not likely to be overstated by respondents. Therefore, backward compatibility of Windows 3 and MS-DOS seems to have facilitated a much slower process of fading out the old operating system, while OS/2 and Windows 3 were less compatible, so that a takeup of Windows 3 triggered a rapid displacement of OS/2, which confirms the results in Table 9.

In summary, there appears to be no systematic increase in the dominance of the mainstream Microsoft OS family over time. However, a number of qualifications are necessary. To start with, dominance has to be defined precisely. Generally, we define dominance as the average share of the sum of all three mainstream Microsoft OS, i.e. DOS, Windows 3 and Windows 95, in each firm. If we look beyond aggregate figures, however, we find a number of tendencies that indicate either increasing or decreasing dominance, resulting in the inconclusive net effect we find in our aggregate figures of dominance. First, there seems to be a tendency to use additional operating systems on a small scale. While in earlier years of our sample most users of the MS family were using exclusively those products, there is a marked tendency to use other OS on a limited number of PCs in the firm. There also is considerable crossing over between the Microsoft standard and OS/2. Early users of Windows 3 have higher usage rates of OS/2 than average, while early users of OS/2 have higher takeup rates of Windows 3. However, users abandoning OS/2 to join Windows 3 apparently do so in a hurry. They are phasing out the incumbent system much faster than previous DOS users. In our data therefore, backward compatibility (between Windows and DOS) does not speed up diffusion of the new technology, but it seems to have a dramatic effect on the speed of phasing out the incumbent technology. The persistence of using the Microsoft family as a dominant system is very high across generations, while, as expected from our previous observations, firms using the Microsoft family exclusively frequently add other operating systems over time.

4 Diffusion and Competition of Operating Systems

In this section, we will analyze the usage of each OS over time. Hereby, we should be able to identify which operating systems display network externalities and/or complementarities and which ones do not. The ones that do not might be assumed to be below their (OS-specific) critical mass and therefore appeal only to "their" niche consumers. Before specifically formulating our regression model, however, we discuss the concepts and expected effects we will be studying.

4.1 Expected Effects

Saturation effect

The takeup of operating system x is subject to a "saturation effect": If a firm has a large installed base (in percentage terms), the bulk of PCs will already have been upgraded to the new system, leaving less computers to be upgraded. Also, if a firm has upgraded early to the current generation of OS, they might be more susceptible to migrate to a succeeding system early. Both these conjectures will have the same net effect: High previous use of x implies less future takeup of x. More formally,

$$\frac{\partial \Delta x_{\mathrm{t}}}{\partial x_{\mathrm{t-1}}} < 0 \qquad \text{(Saturation Effect)}$$

Installed base effect

Generally, the assumption of positive network effects would imply that the speed of adoption depends positively on the installed base within the firm. Since a technology becomes more attractive to an individual user (or in the case of a firm, to a larger subset of users) as more users are already using it, and assuming (sensibly, even though it is a simplification) that every PC corresponds is being operated by one user in the firm, the diffusion speed would increase in a population of agents within the firm. However, our use of percentage of PCs within the firm running on a particular operating system requires some discussion. We define network effects as the positive effect that an installed base in percent of PCs with the firm has on the further takeup of Windows 3. This entails two assumptions: First, we assume that network

benefits are unlimited within the firm. In large firms, this might not always be the case, since sufficiently large populations of users might favour different operating systems so that both systems can be maintained without an overwhelming loss in network benefits. It seems sensible, however, that a firm will only adopt an operating system up to the point when network benefits are exhausted. Therefore, if there are network benefits, the previous installed base will have a positive effect on the takeup up to the point of maximum adoption. In other words, since we are examining the adoption of a new technology rather than the eventual level, the assumption that firms will update only to the level it is still profitable for them, by definition network effects are not exhausted prior to reaching that level. Another issue is the upper bound of 100% of total adoption. If the number of PCs on which system x is installed were available, we could obtain an estimate of the diffusion speed of x in absolute numbers. The relative figure we use has the advantage, however, that it makes diffusion speed of small and large firms (with small and large numbers of PCs, respectively) comparable. As maximum penetration is reached, however, there is less room for additional takeup, thereby slowing down adoption speed. Consequently, we would expect slow takeup for small installed bases, high takeup for intermediate installed bases, and slow takeup again for very high installed bases. Therefore, including the terms x_{t-1} and x_{t-1}^2 will adequately capture the first two parts of the diffusion curve. The saturation effect that kicks in again in the final part of the diffusion curve is expected to decrease the expected positive coefficient on x_{t-1}^2 (with network effect), so that a positive coefficient will be an even stronger indicator of network effects in these cases. Formally, we expect that

$$\frac{\partial \Delta x_t}{\partial x_{t-1}} < 0, \frac{\partial \Delta x_t}{\partial x_{t-1}^2} > 0 \qquad \text{(Network Effect)}$$

Competitive effect

More use of operating system y by definition implies less use of x, which is the essence of the competitive effect. When running a dynamic regression, the competitive effect should persist; i.e. if a firm has been using a competing operating system in the previous period, it is prone to continue using it in the current period (since firms will not upgrade their operating systems every period and there are significant switching cost when migrating operating systems), thereby limiting use of other operating systems. Therefore, we

predict that

$$\frac{\partial \Delta x_{\mathsf{t}}}{\partial y_{\mathsf{t}-1}} < 0 \qquad \text{(Competitive Effect)}$$

if x, y, are competitors.

Complementary and migration effect

Under particular circumstances, high previous use of operating system z can imply higher takeup of system x. Either x and z might be complements, or they might be competitors where x offers significantly higher quality than z. If systems are complements, using both will generate higher benefits than standardizing on one, for example because the OS can perform complementary functions. Since $z_{\mathsf{t}-1}$ is positively correlated with z_{t}, and z_{t} positively correlated with x_{t}, previous usage of z implies higher takeup of x if they are complements. If two OS are competing for the same market (i.e. perform similar functions), and the more recent system, say x, performs better in all dimensions than the incumbent z, then users of z will migrate to x over time. A larger installed base of z then implies higher takeup of x, or,

$$\frac{\partial \Delta x_{\mathsf{t}}}{\partial z_{\mathsf{t}-1}} > 0 \qquad \text{(Complement Effect)}$$

if x, z, are complements or natural replacements.

4.2 Regression model

We develop a set of diffusion regressions taking into account network and saturation effects, and then extend the model to include interactive (i.e. competitive and complementary) effects as well.

Consider a basic model of growth:

$$\Delta x_{\mathsf{t}} = \rho x_{\mathsf{t}-1} + \mu_{\mathsf{t}}$$

This simple model would lead to exponential growth for $\rho > 0$. It is more likely, however, that eventually diminishing returns set in. We extend the basic model by setting $\rho = \rho_0 + \rho_1 x_{\mathsf{t}-1}$, where we expect $\rho_0 > 0$ and $\rho_1 < 0$ in line with a regular S-curve taking into account diminishing returns. If network externalities are significant for a specific OS, however, the signs of ρ_0 and ρ_1 might be reversed; a small installed base yields slow diffusion,

whereas for higher installed base, adoption rates should be higher. Our first diffusion regression is therefore

$$\Delta x_t = \rho_0 x_{t-1} + \rho_1 x_{t-1}^2 + \mu_t \tag{1}$$

Including a time trend modifies equation 1 to

$$\Delta x_t = \rho_0 x_{t-1} + \rho_1 x_{t-1}^2 + \rho_2 t + \mu_t \tag{1'}$$

We run both regressions 1 and (1') for each active operating system and report the results in Table 10. We favoured a random-effects over a fixed-effects specification since the short length of our panel suggests that the time-series variation within firms will be minor, which in turn implies that using fixed effects by mean-differencing the data would strip out most of the variability in our data. Since it is the variability of the dependent variable we want to explain, this approach would lead to too little variation in our dependent variable. Using random effects would yield biased estimates if the sample was distinctly non-random, with respect to the underlying population, but the overall size of our dataset (1686 observations per year) and the negligible differences between balanced and unbalanced sample make us rather confident that using random effects does not weaken our conclusions due to non-randomness. For practical reasons therefore, we chose to model firm effects as random effects rather than fixed effects.

Table 10
Regression equations (1), (1') GLS random effects

	DOS		WIN3		WIN95	
Equation	(1)	(1')	(1)	(1')	(1)	(1')
OS	$-.49^{**}$	$-.53^{**}$	-1.03^{**}	$-.66^{**}$	1.29^{**}	1.05^{**}
OS^2	$-.19^{**}$	$-.22^{**}$	$.32^{**}$	.06	-1.88^{**}	-1.67^{**}
T		$-.03^{**}$		$.1^{**}$		$.04^{**}$
CONS	$.09^{**}$	$.19^{**}$	$.54^{**}$	$.67^{**}$	$.03^{**}$	$-.05^{**}$
R^2 within	.733	.761	.726	.688	.048	.122
R^2 between	.028	.028	.031	.032	.000	.000
R^2 total	.476	.474	.441	.461	.024	.076

Table 10 (ctd.)
Regression equations (1), (1') GLS random effects

	MS TOT		WINNT		WINWK	
Equation	(1)	(1')	(1)	(1')	(1)	(1')
OS	-1.28^{**}	-1.16^{**}	$-.59^{**}$	$-.59^{**}$	$.7^{**}$	$.63^{**}$
OS^2	$.43^{**}$	$.33^{**}$	$-.3^{**}$	$-.28^{**}$	-1.26^{**}	-1.21^{**}
t		$-.04^{**}$		$.01^{**}$		$.02^{**}$
CONS	$.8^{**}$	$.86^{**}$	$.01^{**}$	$-.02^{**}$	$.02^{**}$	$-.02^{**}$
R^2 within	.661	.674	.565	.577	.173	.192
R^2 between	.099	.096	.212	.212	.041	.044
R^2 total	.407	.425	.427	.427	.055	.071

Table 10 (ctd.)
Regression equations (1), (1') GLS random effects

	OS/2		UNIX		MAC	
Equation	(1)	(1')	(1)	(1')	(1)	(1')
OS	$-.72^{**}$	$-.72^{**}$	$-.7^{**}$	$-.7^{**}$	$-.45^{**}$	$-.45^{**}$
OS^2	$-.22^{**}$	$-.22^{**}$	$-.26^{**}$	$-.25^{**}$	$.37^{**}$	$.36^{**}$
t		.00		$.001^{*}$		$-.002^{**}$
CONS	$.02^{**}$	$.02^{**}$	$.001^{**}$	.00	$.002^{**}$	$.007^{**}$
R^2 within	.910	.910	.873	.873	.573	.510
R^2 between	.160	.160	.582	.582	.517	.518
R^2 total	.560	.560	.771	.772	.038	.040

There is an equation (1) for every operating system, so they are, in principle, interdependent, since the percentage-wise uptake of one OS implies a decline of another. The question now is whether other operating systems - say, y_t - affect the equilibrium level of x_t or its rate of growth, i.e. whether 1 should become

$$\Delta x_t = \rho_0 x_{t-1} + \rho_1 x_{t-1}^2 + \alpha y_{t-1} + \mu_t \tag{2}$$

or

$$\Delta x_t = \rho_0 x_{t-1} + \alpha x_{t-1} y_{t-1} + \rho_1 x_{t-1}^2 + \mu_t \tag{2'}$$

Equation 2 yields more significant results for all operating systems, hence we report only the results from 2. In general, we expect higher usage of a competing operating system to negatively influence the usage of another. Should an operating system draw adopters predominantly from specific other

OS, however, we would expect to find a positive coefficient. Results for the full dataset for regression equation 2 are reported in Table 11.

Table 11
Regression equation (2), GLS random effects

	DOS	WIN3	WIN95	MS TOT
OS	-.5**	-.95**	1.22**	-1.29**
OS^2	-.33**	.35**	-1.79**	.42**
DOS		.1	-.01	
WIN3	-.22**		.03	
WIN95	-.14	-.37**		
WINNT	-.04	.01	.005	-.04
WINWK	-.16**	-.21**	.02	-.04**
OS/2	-.1*	.07	-.01	-.03
UNIX	-.06	.21**	-.002	.15**
MAC	-.29**	-.32**	.07	-.47**
CONST	.26**	.44**	.01	.83**
R^2 within	.717	.72	.079	.651
R^2 between	.057	.024	.000	.122
R^2 total	.484	.447	.043	.425

Table 11 (ctd.)
Regression equation (2), GLS random effects

	WINNT	WINWK	OS/2	UNIX	MAC
OS	-.61**	.7**	-.71**	-.7**	-.55**
OS^2	-.3**	-1.25**	-.22**	-.26**	.37**
DOS	-.03*	.01	.00	.00	-.09**
WIN3	-.01	.03	.00	.00	-.09**
WIN95	-.02	-.01	-.01	-.00	-.01
WINNT		.03	-.00	.00	-.05**
WINWK	.05**		.00	.00	-.1**
OS/2	-.09	-.00		-.00	-.09**
UNIX	-.04**	.01	-.00		-.1**
MAC	-.03	-.01	-.01	-.00	
CONS	-.03**	.00	.01	.00	.1**
R^2 within	.571	.188	.91	.873	.353
R^2 between	.211	.034	.161	.582	.166
R^2 total	.432	.064	.56	.772	.084

4.3 Interpretation and Discussion

Saturation and Network Effects

We can see from comparing Tables 10 and 11 that the signs and significance of the installed base effects (i.e. OS and OS^2) do not change with the addition of other operating systems as covariates. Looking at the first set of variables, the effects of the system's own installed base, we find that we can group the operating systems into three different classes, according to the signs of the coefficients on OS and OS^2. We label these classes "losers" - $\rho_0, \rho_1 < 0$, "increasing returns OS (IR)" - $\rho_0 < 0, \rho_1 > 0$, and decreasing returns OS (DR)" - $\rho_0 > 0, \rho_1 < 0$. Figure 4 classifies the operating systems in our sample according to their coefficients ρ_0 and ρ_1.

For loser and IR operating systems, the *saturation effect* is confirmed since $\rho_0 < 0$. On the other hand, network effects do not hold for loser OS. Instead, diffusion speed is negatively affected with increasing installed base and even more so by very high installed bases. This would be consistent with a situation where an operating system is in the process of being phased out,

"loser" OS	increasing returnsOS	decreasing returnsOS
DOS Win NT OS/2 UNIX	Win 3 MAC MS family	(Win 95) Win for Workgroups

Figure 4: Classification of OS.

either because a superior competing operating system or a new generation of the existing OS has been introduced. Indeed, in the cases of DOS, OS/2 and UNIX, this argumentation seems sensible and is confirmed by their average market shares reported in Table 1.[5] Windows NT, however, stands out in this list, since it has been quite successful in the latter part of our sample, when it was specifically designed to complement Windows 95. However, seeing as the final value for an OS' installed base is 1996 (i.e. the year before Windows NT gained market share again), it would appear that in the early parts of the sample Windows NT was a loser OS, and that in the final year the takeup of Windows NT came mainly from "fresh" users of the new generation of Windows NT (which was compatible with Windows 95), i.e. users who did not previously run Windows NT, thereby implying a negative sign for both installed base variables. This is also confirmed by our results in Section 3, where we see in Table 7 that Windows NT was the most popular niche OS in 1997. Thereby, the classification of Windows NT as loser system only applies to the early years, and the developments in the final sample year serve to reinforce the results since additional users of NT were new users with no previous installed base of NT.

The two IR operating systems are Windows 3 and Macintosh. Additionally, the Microsoft family (i.e. the sum of DOS, Windows 3 and Windows 95), also displays an increasing effect of installed base on adoption speed. It is not surprising that Windows 3, which gained strongly during our study

[5]In particular, shares go down from 82.4% to 16% (DOS), 1.6% to 0.2% (UNIX), and 6.1% to 1.7% (OS/2) in the balanced panel, respectively.

period and then established itself as the dominant system, displays network effects. Network effects on the level of the Microsoft family seem fairly intuitive as well, especially in light of the evidence on the persistence of the Microsoft standard presented in Section 3, in particular in Table 6. However, it seems surprising that the Macintosh OS (and hardware, since the two were almost exclusively sold together) should display network effects as well and yet remain at such a low, but stable market share. Our intuition is that Mac users (or users preferring Mac, ceteris paribus) are only a relatively small minority in the population, but that within this niche population Mac displays significant network externalities. In other words, if a potential Mac adopter sees someone else using it, she will follow suit quickly, but non-Mac users will not be swayed even by a sizeable installed base. Therefore, network externalities for the Macintosh could be thought of as strong, but local.[6]

The third category we identify are the decreasing returns (DR) systems. In particular, they are Windows 95 and Windows for Workgroups. DR systems have a positive effect of low installed bases, but a negative effect of higher ones. There are several plausible explanantions for this. First, it could be that there is a "natural percentage" of PCs within a firm that can be equipped with an operating system. This would be synonymous with saying that a certain proportion of tasks is best performed with these operating system, but that other tasks (which would imply a percentage higher than the "natural rate") are best left to other OS, thereby causing decreasing returns to set in beyond a certain installed base. This would appear ot be the case with Windows for Workgroups, which was marketed as a low-cost, low-end alternative to more expensive, networked operating systems within the Microsoft family, such as Windows NT or even Windows 95. Therefore even in larger firms, Windows for Workgroups might be used for simple communications tasks, e.g. email terminals, while more demanding or specialized tasks would require other OS, hence imposing a natural limit on usage of Windows for Workgroups. In the case of Windows 95, this explanation does not hold, especially in the light of recent history, when Windows 95 succeeded Windows 3 as the leading operating system. Windows 95 in our sample was clearly at a very early stage of its diffusion, which might explain the set of coefficients we obtain. It seems intuitive that the saturation effect has

[6] We find support for this hypothesis across firms in Geroski and Kretschmer [**?**]. There, we identify strong intra-industry network effects in the use of Mac, which is further evidence that Mac users are alike in some important respects.

not yet set in directly, so that firms who have a positive installed base of Windows 95 are already in the process of upgrading to it, thus explaining the positive installed base effect. The saturation effect might consequently only become more important for higher installed bases, so that the saturation effect dominates the network effect for intermediate installed bases, thus yielding a negative coefficient for the square term.

Competition, Complementary and Migration Effects

From the second section of Table 11, we can see that most cross-OS coefficients are negative, as expected. This confirms our *competition effect*, that more use of one operating system implies less takeup of another, competing one. There are two exceptions, however: The diffusion speed of Windows 3 is positively and significantly influenced by the installed base of Unix, as is the diffusion speed of Windows NT by the previous usage of Works for Windows, suggesting a possible *complementary* or *migration effect*. We believe that this has different explanations in the two cases: Windows 3 may, as we have seen in the previous section, have succeeded in winning over users of competing systems. One of the strengths of proprietary versions of Unix is the user interface that is easier to use and more powerful than DOS, but Windows 3, by introducing a graphcial user interface, could close that gap. This also seems intuitive given that the main users of Unix (even though we do not have demographics for this particular dataset, this is commonly accepted industry wisdom) were networked, larger companies, and Windows 3 precisely addressed the weaknesses DOS was faced with when trying to cater to this clientele. On the other hand, the main explanation for the Windows NT - Works for Windows complementarity is that Works for Windows and Windows NT are complements on either end of the market. Users of Works for Windows might discover that their current system cannot fulfil all the functions required and decided to add another operating system that specifically fills this niche, but does not duplicate the effort by buying a system similar to the one already used, as for example Windows 3 or Windows 95 would have.

5 Conclusions and Outlook

Our paper shows that not all firms in a seemingly highly standardized industry are standardized themselves. In fact, a large number of firms at any

point in time are in the process of upgrading, outphasing, or introducing an operating system on at least part of their PCs. This has led us to investigate a stylized facts in the operating systems industry and a series of questions pertaining to the dynamic behaviour of firms when deciding on intra-firm standardization and upgrading of operating systems. It seems that at least part of the non-standardization phenomenon can be explained by the process of 'permanent transition' that the market for operating systems is going through and that firms are always replacing an old system, installing a new system, adding a fringe system and discarding another. It has to be observed, however, that even though in the four-year period of our first dataset (1994-97) two systems, MS-DOS and Windows 3, have been the dominant systems, and Windows 95 was in the process of taking off, the average market share of the fringe operating systems has remained relatively constant. However, we found that the degree of dominance within firms apparently has changed progressively over time; firms are increasingly likely to use additional operating systems on a small fraction of their PCs, which could be due to the increased pace of introduction of new Windows generations or the increased needs of firms to fulfill more varied tasks, thus requiring more diverse operating systems. Another tendency seems to further reinforce Microsoft's dominance, although not through their mainstream systems, but through the introduction of more varied systems themselves. In particular, it seems that in the early part of our sample, firms starting to use additional operating systems would opt for non-Microsoft systems, in recent years the preferred fringe systems were other, specialized systems by Microsoft. Therefore, Microsoft has captured the market opportunities arising from more varied needs on an operating system themselves by covering more of the marketspace through other systems.

Regressions of the takeup of individual operating systems as a function of lagged usage has shown that there seem to be three groups of operating systems - OS with significant network externalities, OS displaying decreasing returns to adoption, and OS that seem to be in the process of vanishing or phasing out. We find that Windows 3 is the main driver within our study period of network effects for the Microsoft family (since both DOS and Windows 95 did not display network effects in our regressions), while there exist significant network effects for Macintosh OS, which corresponds to the notion that Apple Macintosh users are different and therefore form a niche

with strong network externalities.[7] For Windows for Workgroups, a low-end OS substitute with the look and feel of Windows, the regressions suggest a "natural rate of usage" beyond which decreasing returns set in. For most of the early competitors of the Microsoft standard and Microsoft's first OS itself, DOS, we find negative effects on the diffusion speed by the current installed base, which corresponds to an operating system in the process of decline.

Our study of the operating systems industry is an interesting example of competition and market dynamics in a highly concentrated market. It has shown that even with a strongly dominant firm occupying several niches in the market, other competitors can maintain a small, but stable market share. It has to be noted, though, that our market for OS is a specialized market with features not common in other markets. For a start, few firms can maintain a market share consistently higher than 85% for their bread-and-butter products, not counting specialized products (such as Windows NT and Windows for Workgroups). In addition, the dominance of Microsoft on the complementary goods market is almost unprecedented, which will have further implications for entering firms. In summary however, we believe that this study will be generalizeable to a certain extent to other end-user electronics markets with significant network effects complementary hard- and software markets with heterogeneous consumers. The particular market structure of a near-monopoly in two related markets, however, will put a limit to the applicability of our results.

An interesting problem to explore in our context, however, is the question of how firmwide dominance translates into industrywide dominance. If network effects are already exhausted even within the firm, how can Microsoft still dominate the market? The mechanics of this phenomenon are likely to be quite different from the standard explanation of significant and almost unlimited network effects in the OS market, as our study has shown. We hope that through this study we have provoked further discussion and investigation into this subject.

References

[1] Arthur, W. B., Ermoliev, Y., Y. Kaniovski (1987): Path-dependent

[7] One of Apple's slogans is "Think different", and one of their commercials addresses "The crazy ones. The misfits. The Rebels. etc." (http://www.apple.com/thinkdifferent).

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