Operating System Prices in the Home PC Market

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Abstract

The pricing strategy of OS producers was a key issue in the Microsoft antitrust case. Economists working for Microsoft have argued that the low price of Windows is not consistent with a durable monopoly power and reflects more likely the outcome of a potential or effective competition. To investigate this empirically, we recognize that the demand of operating system is a derived demand revealed through the demand for computers. We fit a structural model of the home PC market to a panel data set providing shipments, prices and characteristics of most PC brands sold for home use in Canada, France, Germany, Italy, Japan, UK and US over the period 1995-1999. The demand side is specified according to a nested-logit model. Market outcomes are endogenously derived in the context of a Nash equilibrium. We report three main results. First the relevant market encompasses all PCs whatever the installed OS. Second the profit-maximizing price of DOS/WIN that would result from our static equilibrium is much higher than the observed price. Third, at the present price of its OS, Microsoft's behavior could be viewed as putting more weight on its market share than on its present profit. These results call for a dynamic approach.

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1. INTRODUCTION

Suppose you have built a personal computer from your imagination. Like Geppetto in front of his wooden puppet, you dream to make it alive. All you need is an operating system (OS).[1] That the pricing of this life source is at the core of a famous antitrust trial should then be no surprise, especially as the place of PCs in the economy has grown considerably during the last two decades and, more importantly as their utilization now significantly affects the productivity statistics.[2] Recognizing that the demand of operating systems is indeed derived from that of PCs on which they are installed, this paper explores the economic rationale of present OS prices empirically.

A computer operating system is aimed at providing several services. First it allows the user to interact with the computer and to access the information stored on various media. Second it loads programs into memory and executes them. Third it provides services to software applications – known as application programming interface – that makes application writing easier and more efficient. This latter function plays a crucial role in the debate for a reason that could be summarized as follows. The more convenient the access provided by the operating system to the computer, the easier it is to develop applications, the more applications can be written, and the larger the audience of the operating system. This mechanism provides the fuel for a network effect that could eventually allow an operating system to cannibalize a competitor with a less efficient or convenient access system. It happened to DOS when Windows 3.1 was introduced.[3]

Besides operating systems, other software products can provide services to applications. Programs that offer to software developers a way for accessing subroutines that perform standard functions, like printing a document, are called *software platforms.* An example of a software platform is the so-called *middleware* program that is placed between the operating system and software applications. The developer of an application using exclusively the services provided by a middleware program knows that his/her application runs on any operating system for which the middleware program has been already developed. In this case the operating system becomes less valuable than the middleware, which is clearly a source of competition.

An example of a middleware is Lotus Notes and examples of actual or potential software platforms include Windows 2000, Linux, OS/2, MacOS, Web sites and Web browsers. That these products belong to the same software category is exemplified by Windows, which is "a classic example of middleware that evolved to a platform and eventually to an operating system" as explained by Evans [2000]. It does not mean that the differences among these products are negligible from an economic point of view; it just means that the competitive relationship among them is an interesting

[1] The source of this allegory is borrowed from Petzold [1999].
[2] See for instance Jorgenson [2001].
[3] This example is drawn from Liebowitz and Margolis [1999]. For an empirical paper on the role of software development in the competition between operating systems, see Gandal, Greenstein and Salant [1999].

and indeed debated issue. That the level of competition between software platforms can be strong is illustrated by looking at the market for server operating systems where products like Windows NT or Linux have been able to take significant market shares in a few years, mainly to the detriment of Unix and Netware environments.[4]

The debate on the price of Windows takes place in this context. The Court's Findings of Fact for the *U.S. et al. v. Microsoft* case asserts that Microsoft has a dominant share in the relevant market, i.e., 95 percent of the licensing of all Intel-compatible PC operating systems worldwide.[5] In addition it asserts that this market share is protected by a barrier to entry itself created by the large number of applications developed (sometimes solely) for the Windows platform. Finally, it asserts that customers do not have a "viable alternative." In these conditions, Microsoft is presumed to have a monopoly power, that is to say, to be able to maintain its prices above competitive levels. Microsoft's defense challenges this view using an argument developed by Reddy, Evans and Nichols [1999] and simplified as follows.

Each PC sold comes with an operating system. Then, assuming that PCs are homogenous products, the elasticity of demand for operating systems is that of the demand for PCs times the ratio of the OS price to the price of PCs.[6] Now, suppose that the developer of operating systems is a monopolist and the marginal cost of producing operating systems is zero. The profit-maximizing monopolist selects the price at the point where the demand elasticity for the OS is equal to unity. Suppose the elasticity of demand for PCs is slightly greater than one. Then the ratio of the OS price to the price of PCs must be slightly smaller than one for the monopoly equilibrium condition to hold. Then profit-maximizing price of the OS might be of the magnitude of the price of PCs, i.e., might be much higher than the present prices of OS (even if the latter includes complementary revenues that are triggered each time a specific OS is installed on a PC).

For Werden [2001a], the discrepancy between the observed price of Windows (around $60) and what is expected from this argument (i.e., something in the magnitude of the price of PCs, namely several hundreds dollars) can be explained by the fact that the argument does not account for PC heterogeneity.[7] However the plaintiffs' and defendant's sides at the antitrust trial agree on other economic reasons for explaining the price gap. Basically, the body of reasons focuses on the idea that the above argument is cast in a static world, which does not take into account the role of network effects, the competition between the different releases and updates of OSs or the effect of piracy. (See, on these questions, Schmalensee [1999], Fisher [1999], Fisher and Rubinfeld [2000], and Evans and Schmalensee [2000].) The agreement ends here. On the one hand, the level of observed OS prices

[4] See International Data Corporation [1999b] on operating systems.
[5] According to International Data Corporation [1999b], Microsoft's share in worldwide PC-OS total shipments reaches 89 percent in 1998.
[6] Implicitly it is assumed that the OS price is passed on to consumers.
[7] Werden's conjecture has initiated an exchange of replies between Reddy *et al.* [2001 a and b] and Werden [2001b].

is the outcome of a potential or effective competition. On the other hand it is compatible with a firm having a monopoly power.

This paper contributes to this debate by performing an econometric test on real data. Clearly one of the key issues here is the level of the elasticity of demand for operating systems. Behind the argument presented by Reddy *et al.* [1999] and Schmalensee [1999] is the idea that the demand for operating systems is a derived demand as it is indirectly created by the demand for PCs. The rules governing derived demand has been known since Marshall.[8] A low elasticity of derived demand for a specific input is expected if there is a lack of substitutes, the demand for the final product is inelastic, the expenditure on the input is a small fraction of the total production cost of the final product, and the supply of other productive services entering the product is inelastic. Our objective here is to examine to what extent these conditions are met in the case of operating systems. Putting aside the fourth condition and considering that the third one is satisfied for any PC, our attention is focused on the first two conditions.

To empirically test these conditions given what has been said so far, we estimate the demand for PCs in order to infer the elasticity of demand for operating systems. To do so, we must account for the apparent high degree of differentiation in the PC industry. Indeed each PC brand is likely to face a different demand elasticity, which is critical for our purpose. The literature on differentiated products, and in particular the econometrics of differentiated product markets, shows that this requirement is best addressed through a structural model of demand and supply. The econometric literature on the PC industry has already recognized this requirement. Indeed Stavins [1997] presents two-stage least squares estimates of demand elasticities taking into account changes in market structure. Bresnahan, Stern and Trajtenberg [1997] find the sources of transitory markets power in the different forms of segmentation they distinguish in the PC industry. For evaluating the effect of computerization, Hendel [1999] explains the choice by business firms to buy multiple-brands through a random utility model that accounts for supply effects.

Note that, although Stavins and Bresnahan *et al.* use aggregate data on sets of PC brands for the US PC market and Hendel exploits a survey of US establishments, they all obtain relatively high elasticities at the brand level. As these results do not a priori imply a low aggregate elasticity, which is implicitly needed in the argument presented by Reddy *et al.* [1999], the question of deriving an estimate of the aggregate elasticity of demand for PCs (and hence for OSs) is crucial. However to estimate an aggregate elasticity, data that cover the whole market are required. Such data are compiled by International Data Corporation (IDC). From the whole IDC database, we consider here a panel data set providing shipments, prices and characteristics of most PC brands sold by all vendors present in at least one country among the G7 countries, i.e., Canada, France, Germany, Italy, Japan, UK and US, over the period 1995-1999. In addition, we restrict the scope of the study to the home

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[8] We thank Jerry Hausman who raised this point and mentioned to us the excellent presentation of the rules of derived demand by Stigler [1987]. See also Whitaker [1991].

segment for a technical reason among other reasons that are discussed below. Large businesses, for example, typically purchases and own multiple PCs, while this is much less true of home users. By concentrating on the home segment, we can largely ignore the question of how to handle purchases of multiple units. Restricting attention to the home segment is not too limiting. Not only is the home segment large, but it also plays a crucial role in the evolution of the information technology industry.[9]

One important limit of our model is that it does not account for network effects, which play a crucial role in this industry. Later we argue that we empirically identify some effect of the installed base of PCs on the valuation of PCs, this effect being one possible proxy for network effects. However we do not account for the feedback that the effect of the installed base of PCs can have on the supply and pricing decisions. A proper way to empirically measure and identify network effects is still on the research agenda. In a very convincing way, Bresnahan [2001] recognizes the difficulty of this task and provides documentary methods to test the theory of network effects in the context of the Microsoft lawsuit. We believe that, in order to identify network effects, one should favor a dynamic framework and one should observe the process on a substantial number of periods. This last condition is not satisfied in our case. Indeed, already in 1995, the home PC market is saturated and dominated by the Wintel platform, i.e., PCs equipped with an Intel processor and a version of Windows. Here, we let aside here the question of estimating an empirical model integrating network effects and we focus on the working of the home market in a static set up.

The data are extensively discussed in section 2. Based on the features of our database, we devote section 3 to the presentation of a structural model of the home PC segment allowing for heterogeneous products. This model is based on two main ingredients. First, in the line of a tradition initiated by Berry [1994], the demand side is specified according to a nested-logit model. Second, quantities and prices are jointly derived from an assumption of Nash equilibrium prices. In section 4, the model is fitted on the panel data set. Then, using the parameter estimates, we obtain the aggregate elasticity of demand for operating systems. In section 5 we proceed to counterfactual exercises for evaluating the profit-maximizing prices of operating systems. Results are summarized in section 6 that concludes.

II. DATA AND DESCRIPTIVE ANALYSIS

The database assembled by International Data Corporation (IDC), a well-known market research firm in the microcomputer industry, is suitable for our project.[10] The IDC PC Tracker

[9] See Cusumano and Selby [1998] for instance on the role of the home market..

[10] This section extensively uses documents and reports from IDC provided to us by Microsoft. (See the references.)

database provides breakouts of PC shipments and prices by vendor,[11] brand,[12] form factor,[13] processor speed, region and customer segment. Quarterly data are available since 1995. With the fourth quarter of 1999 as the last quarter available when we began the estimation, the database covers 20 quarters. We restrict attention to the seven countries of the former G7, i.e., Canada (CA), France (FR), Germany (GE), Italy (IT), Japan (JP), United Kingdom (UK) and the United States (US).

The choice of the home segment

Among the different customer segments, the home segment is a sensible candidate for this study for at least three reasons. First, the set of assumptions that we must introduce for analyzing this segment seems reasonable. In the model below, all we need is a representative consumer or household buying one PC. In the case of other segments like business or government, the demand for information technologies is a complex and collective issue that should require more sophisticated models.[14] For instance one might need to account for inputs other than PC hardware and for PC purchase contracts that often involve quantity discounts and nonlinear prices. Second, the home segment is significant share of the total industry shipments. So it has a strong impact on the equilibrium of the hardware industry as a whole. Note that it amounts to 36 percent of total US unit shipments and to 31 percent of total US sales revenues on average over the period 1995-1999. Note also that US households account for roughly half of the total US installed base of PCs.[15]

A third reason for choosing the home segment is purely technical. The type of operating system that is installed on each computer shipped is not observed or not reported in the IDC database, which is of course unfortunate. However, according to IDC, a PC "is a computer with an Intel-architecture (x86, including compatibles) microprocessor, designed primarily as a single-use device, capable of supporting attached peripherals, and programmable in high-level languages that can run an off-the-shelf PC operating system such as DOS, Windows or OS/2, and that carries a configured price of less than $25,000 (U.S.). Additional products counted as PCs include the following: Computers with PowerPC processors, designed primarily to run the Macintosh OS, that otherwise meet the basic criteria; Any product that meets the definition of PC server,[16] even though PC servers are not single-user devices (…)."[17] Given this definition, the choice of the home segment for performing our study is dictated by the fact that it facilitates the identification of the OS installed on each of the computers

[11] A vendor is here a company that manufactures hardware. For this reason it is often called a system vendor.
[12] A brand is the commercial name of a PC.
[13] "Form factor" is a technical term used to define the form of a PC, whether it is a desktop, a PC server, a notebook or a portable. See below.
[14] In 1998 IDC reports that one third of PC households in the US had more than one computer at home. This ratio seems stable, but the number of PCs owned by multiple-PC households is increasing. We neglect here the question of multiple-PC users, which could correctly be addressed only through household surveys.
[15] This last point is discussed again later.
[16] According to IDC, a PC server is a machine expressly built, marketed, and sold as a server!
[17] According to IDC, "exceptions to the PC definition are as follows: Smart handheld devices (…); Any product, such as a terminal or network computer (NC), that is designed primarily to access information on another computer (…)."

whose shipments are measured in the IDC database. Indeed by considering the home market, we are left with only two platforms, each characterized by a single family of processors and a single family of operating systems. The first platform gathers all variants and versions of DOS and Windows installed on machines powered by Intel-compatible.[18] The second platform is mainly produced by one vendor, Apple, and combines a version of the MacOS with a Motorola or PowerPC processor.[19] In other terms, by focusing on the home segment we restrict our attention to computers for which the relationship between the processor type and the (unobserved) OS is essentially one-to-one.

The first platform, herein called the DOS/WIN platform, has a large share as shown on Figure 1. Note that the market share of the competing platform, herein called the MacOS platform, is much larger in Japan than in the other G7 countries.

Features of the home segment

All together our database on the home PC market contains 23701 records. In addition to the number of countries and period, this large size is explained by the number of vendors per country. Considering each country separately, seventeen firms on average have an annual market share larger than one percent for at least one year over the period 1995-1999.

Behind the curtain, one sees an industry with "local" firms sometimes quite large in a single country but often quite small, and with multinational firms often with relatively small market shares outside their home countries. From inspecting the data, one can indeed notice the followings. The number of vendors shrinks to seven when we restrict attention to firms that passed the one-percent market share threshold in each of the five years over the same period. Only four firms are present in the seven countries with the same criteria. Table 1 reports the names of vendors that belong to the top 10 in at least two countries over the period 1995-1999. Note that the list is quite different from one country to another. In each country there are "national champions" that are not present in the other countries.[20] This can be observed by looking at the market shares achieved by vendors that we gather in the category "Other top 10", i.e., by vendors that are in the top 10 in only one country.[21]

Table 2 displays the G7 shipments and market shares for the ten largest firms in each year. Note that the ranking evolves significantly over time. Given these facts, a reasonable conjecture is that the home PC segment experiences fierce competition. To complete this view, Table 3 offers some statistics on the empirical distribution of market shares at the brand level per country and year. Note

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[18] A PC powered with an Intel processor could be shipped with Linux, OS2, or some other operating systems. Unfortunately, our data do not let us identify such shipments. However such cases should be very rare for the home segment over the time period considered here.
[19] A few vendors with negligible market shares also have sold Macintosh clones. They are considered as competitors of Apple within this platform.
[20] Differences among countries could be in part explained by differences in the structure of distribution channels of PC products. Again, this question is not addressed here.
[21] Some vendors are unknown in the IDC database, and have been gathered in a category named "Others." This ad hoc vendor has a larger aggregate share than the largest single vendor in a country. Of course this vendor in the top 10.

that the mean is smaller than a half percent and that, for most countries, the largest market share decreases as time goes.

Differentiation is not an empty word in this industry. The number of brands present in the home PC market of a country in a given year is quite large with an overall mean of 79 brands per country and year.[22] For most countries the number of brands, which is correlated with the population size, is slightly increasing over time. (See Table 4.) A crucial dimension of differentiation between computers is provided by the forms PCs can take, the so-called factor forms. For the home segment, three form factors are usually identified: Desktop, laptop or notebook, and ultra portable.[23] From statistics not reported here, one observes that desktop computers have an overwhelming share that reaches 95 percent on average, except for Japan for which this share is 62 percent. The Japanese market is indeed more inclined to portable PC than the other markets.

Another product characteristic that could be a candidate for market differentiation is the speed of processors. Table 5 displays the different generations of Intel-compatible processors. It shows the very rapid change in the processor speed: Each year sees a new processor with an increased speed. In a given year, most PC brands that are shipped to different destinations can be equipped with five leading types of Intel processors. (See also Table 4.) However, the length of life of each Intel processor generation is around three years. Moreover, as soon as a new generation arrives, the old one disappears from the market. Our conjecture is that this dimension of differentiation should only be meaningful in an intertemporal approach. Concerning the MacOS platform, the IDC database allows us to distinguish three types of Motorola processors: 68030 and below, the 68040 (at a 25 - 33 MHz speed) and the PowerPC. Unfortunately the shipments of MacOS-type computers are not broken down according to the different speeds of the PowerPC microprocessor.

Finally, the database also provides prices of the different brands. Indeed IDC computes for each brand an "Average Selling Price" which is "the average end-user (street) paid for a typical system configured with chassis, motherboard, memory, storage, video display, and any other components that are part of an "average" configuration for the specific model, vendor, channel and segment." Based on these prices, Table 6 shows the temporal patterns of annual average prices for each country. Note the decreasing trend that could support the view that competition is getting fiercer over time. In addition Table 6 provides the standard deviations of the price distribution in each year and in each country. It indicates high price variability. Note for instance the high levels of price means and variances in

[22] This number could be slightly overstated as we consider that unknown brands (that enter in the other category) are different from the known brands.

[23] A desktop is a form of PC that is not intended to be mobile and that is not a server. A laptop or a notebook is a portable of medium weight that includes a floppy disk drive and an LCD. An ultra portable is a portable even smaller and lighter than a laptop, which has no floppy disk drive.

Japan in contrast to the low levels in Italy, which is in part due to differences of technical characteristics of PCs shipped in these two countries.[24]

The data, the model and the household decision set

The model below is built from the preceding facts and remarks. Given our data, choices in three areas seem relevant: form factor, client operating system, and brand. All other possible choices that a household can face when buying a PC, like the choice of monitor size, for instance, cannot be observed here. The choice of the type of processor is mainly linked to the choice of platform. It is a technical feature that evolves over time independently of the consumer choice and that mainly modifies the general desirability and cost of the machine. We believe that the choice of a processor speed does not reveal anything on the activities of the household. By not considering the processor types and speeds as distinct dimensions, our model does not allow for the possibility that, for instance, consumers substitute more between Pentiums than between a Pentium and a 486. As we notice in the descriptive analysis above, each new generation of processor rapidly drives an old one out of the market. Even within a generation, the different versions are disappearing rapidly. For instance, in our database, it is not possible to find a Dell Dimension equipped with a Pentium 6 running at 400 MHz and the same brand equipped with a Pentium 6 running at 200 MHz in the same country (market) and the same quarter. The differentiation in terms of processor type would only be meaningful a more dynamic structure.

Two possible (realistic) sequences of choice seem worthy of investigation, with the last dimension of choice being the choice of brand. The first sequence consists of choosing the PC form, the operating system, and finally the PC brand. It is a standard order of choice in the sense that the hardware form is selected before the software. The second sequence just inverts the first two decision levels. This order could be even more realistic when the customer is aware of the working of a PC product and its environment.

For ease of exposition, the model is cast in terms of the first sequence. The choice between the two sequences is left as an empirical issue.

III. THEORETICAL MODEL

One of the key features of the data is the high degree of price and product differentiation. The structure that we consider here in order to analyze the working of the home PC segment follows the model proposed by Verboven [1996]. It allows us to characterize supply and demand side effects that could explain price differences and the behavior of vendors. This model has two main components: a

[24] Table 6 is here to illustrate the trend and the variability of prices. Of course the mean values are not price indices It means in particular that the means are not computed to account for differences in characteristics.

demand system, which is based on the nested logit model, and a supply system derived from a Nash equilibrium.

Demand system

Consider that there are *M* separated markets, each market $m = 1,....,M$ being defined as a country at one period. Let N_m be the potential market size corresponding to the total number of potential consumers. In much of what follows, we drop the index *m* for simplicity.

Each consumer $n = 1,...,N$ can buy one and only one computer in one market, or each can buy an "outside good.» That outside good could be a substitute to the use of a new computer, like a computer already in use at the consumer home, a handheld computer, or a network computer, or it could be no computer at all.[25] In the first stage of choosing a computer, the consumer selects one of the three PC form factors or the outside good *O*. There are three possible form factors: desktop *DT*, laptop *LT* and ultra portable *UT*. Let *g* be the choice made by the consumer in the choice set $G = \{DT, LT, UT, O\}$. In a second stage, the consumer chooses between two client operating systems, namely DOS/WIN and MacOS. Let *h* be the operating system selected by the consumer in the set H_g of operating systems available conditional on the choice *g* in the first stage. In our case, both operating systems are available for all three form factors, so the two operating systems are always available, i.e., $H_g = \{WIN, MAC\}$ for any *g*. Finally, in the third stage the consumer chooses one brand k in the set K_{gh} of PCs available conditional on the choice (h, g).

The indirect utility level achieved by consumer *n* from the choice of brand *k* using the operating system *h* installed on a specific form *g* is given by

$$U^n_{k(h,g)} = V_{k(h,g)} + e^n_{k(h,g)}, \tag{1}$$

where $V_{k(h,g)}$ is the mean utility level that is assumed to be common to all consumers and $e^n_{k(h,g)}$ defines the unobserved variables that explains the departure of consumer *n*'s behavior from the common utility level. The mean utility can be further decomposed as

$$V_{k(h,g)} = \bar{V}_{k(h,g)} - a\, p_{k(h,g)} + x + x_{k(h,g)}, \tag{2}$$

where $\bar{V}_{k(h,g)}$ is a deterministic part that depends on the specific brand, operating system and form factor chosen by the consumer, x is a market specific component, $x_{k(h,g)}$ is a random term reflecting the effect of unobserved characteristics of brands on the mean utility, $p_{k(h,g)}$ is the price of the selected product and a is a parameter of interest to be estimated.

[25] On the market for handheld computers, see van Wegberg [1998].

The random part $e^{n}_{j(h,g)}$ is specified as a weighted sum of unobserved variables as follows

$$e^{n}_{k(h,g)} = n^{n}_{g} + (1 - s_{H}) n^{n}_{h(g)} + (1 - s_{K}) n^{n}_{k(h,g)}, \quad \forall n = 1,\dots,N \tag{3}$$

where s_H and s_K are parameters to be estimated. The random components are assumed to be distributed in such a way that n^{n}_{g}, $(1 - s_{H}) n^{n}_{h(g)} + (1 - s_{K}) n^{n}_{k(h,g)}$ and $e^{n}_{k(h,g)}$ each has a standard extreme value distribution. Given that the consumer cannot buy outside the market where she is located, these assumptions give rise to the nested logit model. (See Appendix A.)

This model allows us to decompose s_k, the unconditional probability of selecting a PC *k*, as the product of three conditional probabilities: i) $s(k|h,g)$, the probability of choosing brand *k* conditional on the form factor g and operating system h; ii) $s(h|g)$, the probability of choosing the operating system h conditional on form factor g; iii) and $s(g)$, the probability of choosing PC form *g*. Recall two important features of this model. First the higher s_K, the higher the correlation between products of the same sub-group, i.e., the same client operating system, and the higher s_H, the higher the correlation between products of the same group, i.e., the same form factor. Second, the parameters must satisfy $1 \geq s_K \geq s_H \geq 0$ for the model to be consistent with economic theory. (On these points, see Ben-Akiva and Lerman [1985] for instance.)

Finally, aggregating these probabilities over all consumers generates market shares. Using simple algebra and some normalization detailed in Appendix A, s_k, the unconditional share of product *k* in a market,[26] can be written in logarithmic form as

$$\ln s_k = \bar{V}_{k(h,g)} - a\, p_{k(h,g)} + s_K \ln s(k|h,g) + s_H \ln s(h|g) + \ln s_0 + x + x_{k(h,g)}, \tag{4}$$

where now $s(k|h,g)$ designates the share within the nest defined by form factor *g* and operating system *h*, $s(h|g)$ is the share of the operating system within the nest defined by form factor *g*, and s_0 is the probability of choosing the outside good.

The different shares are measured as

$$\begin{aligned} s_k &= q_k / N, \\ s(k|h,g) &= q_k / Q_{hg} = q_k \Big/ \sum_{k \in K_{hg}} q_k, \\ s(h|g) &= Q_{hg} / Q_g = Q_{hg} \Big/ \sum_{h \in H_g} \sum_{k \in K_{hg}} q_k, \end{aligned} \tag{5}$$

[26] It is noticeable that the shares involved in the econometric model are not conditional on purchases being made (because we account for the outside good) as are "market" shares involved in the descriptive analysis. We devote the term "market share" to conditional shares.

where Q_{hg} is the total quantity of products belonging to the nest (h,g) shipped by all firms present on the market, and Q_g is the total quantity of products belonging to the nest g. These variables are used in Appendix B for deriving the expressions for the various elasticities, i.e., own-price elasticity, cross-price elasticity within the same group *g* and the same sub-group *h*, cross-price elasticity within the same group *g* and between different sub-groups *h* and cross-price elasticity between different groups *g*.

Supply system and equilibrium

Consider a vendor *f*. Let S^f be the set of PCs that firm *f* offers on one market. The vendor chooses the set of prices for maximizing profits, i.e.,

$$\underset{\{p_k, k\in S^f\}}{\text{Max}} \sum_{k\in S^f} (p_k - c_k) q_k \ , \tag{6}$$

where c_k, the marginal cost of producing brand *k*, is constant.[27,28] Assuming a Nash-Bertrand competition for the home PC industry in each separated market, and considering the demand function as specified in the preceding section, Appendix C provides, for each product *k* that belongs to the nest (h,g), the expression of the markup p_k, i.e.,

$$(p_k - mc_k) = \frac{1}{a}\left[\frac{1}{1-s_K} - r_{hg}Q_{hg}^f - r_g\Gamma_{hg}\sum_{h'\in H_g-\{h\}}\frac{Q_{h'g}^f}{\Gamma_{h'g}} - r_0\Lambda_{hg}\sum_{g'\in G-\{g\}}\sum_{h\in H_{g'}}\frac{Q_{hg'}^f}{\Lambda_{hg'}}\right]^{-1} \equiv p_k\,, \tag{7}$$

where $Q_{hg}^f = \sum_{j\in K_{hg}\cap S^f} q_j$ is the total quantity of products belonging to the nest (h,g) shipped by firm *f* and

[27] In this sense the technology exhibits constant returns to scale, as we do not account for fixed costs that would play a role only the entry-exit decision of firms. We have tested more flexible specifications for the cost function allowing for increasing or decreasing returns to scale. Under these alternative models, the other parameters of interest did not change significantly, and hence the conclusions are similar to those we derive under the assumption of constant marginal costs. For this reason we do not report these further experiments. For the sake of completeness, we note that our estimated returns were always slightly increasing, which is consistent with the structure of the PC manufacturing industry. However, we believe that analyzing this question requires a richer data set on costs in order to be able to construct meaningful cost functions of firms in this industry.

[28] Note that here we are concerned by producer prices, i.e., net of the cost of OS. (For Apple we can imagine that the hardware and software departments are separated). The difference between producer and consumer prices is only made when it is explicitly required.

$$\begin{cases} r_{hg} = \left(\dfrac{1}{1-s_K} - \dfrac{1}{1-s_H} \right) \dfrac{1}{Q_{hg}} + \dfrac{s_H}{1-s_H} \dfrac{1}{Q_g} + \dfrac{1}{N}, \qquad r_g = \dfrac{s_H}{1-s_H} \dfrac{1}{Q_g} + \dfrac{1}{N}, \qquad r_0 = \dfrac{1}{N}, \\ \Gamma_{hg} = \left[\dfrac{1}{1-s_K} + Q_{hg}^f \left(r_g - r_{hg} \right) \right], \qquad \Lambda_{hg} = \dfrac{1}{1-s_K} + \left(r_0 - r_{hg} \right) Q_{hg}^f + \left(r_0 - r_g \right) \Gamma_{hg} \sum_{h' \in H_g - \{h\}} \dfrac{Q_{h'g}^f}{\Gamma_{h'g}}. \end{cases} \tag{8}$$

The existence of a solution to the set of Equations (7) for all products of each vendor present on the market is based on results derived by Caplin and Nalebuff [1991] and by Anderson, De Palma and Thisse [1992]. Note that Equations (7)-(8) show that the markup takes values on a restricted set. Indeed it is only determined by three parameters of interest a, s_K, s_H, and by the aggregate quantities associated with the nests of upper levels of the decision tree. In other words the number of nests plays a crucial role on the continuity of the function defining the markup.

IV. EMPIRICAL ANALYSIS

The demand equation (4) and the pricing equation (7) form a simultaneous equation system in the sense that prices and quantities are jointly determined. This system can be estimated by applying the nonlinear three-stage least-squares estimator, once some additional assumptions are made.

Econometric specification

The deterministic part of the indirect utility is specified as a linear combination of available exogenous variables, like firm-specific effect and dummy variables for the types of OS, PC form factor, and processor that characterizes a particular brand. The market-specific variable x is specified as a set of dummy variables referring to the different countries and time periods, also allowing for the cross effects between countries and firms and between countries and OS. Let x be the set of all these variables. Then, reintroducing the market index m and using the notations introduced so far, the demand equation is stated as

$$\ln \frac{q_{km}}{N_m - \sum_{k \in K_{hg}, \forall h,g} q_{km}} = x_{km} b - a_m p_{km} + s_K \ln \frac{q_{km}}{Q_{hgm}} + s_H \ln \frac{Q_{hgm}}{Q_{gm}} + x_{km}, \tag{9}$$

where b is a vector of parameters to be estimated. Note that the parameter a is now made country specific. The precise elements of the vector of exogenous variables are given below with the estimation results.

Concerning the pricing equation, we must specify an expression for marginal cost. We assume that

$$c_{km} = \exp\left(x_{km} g + z_{km} \right), \tag{10}$$

where g is a vector of parameters to be estimated and z is a random term that stands for the unobserved component of the marginal cost.[29] Based on Equation (10), the pricing equation becomes

$$\ln\left(p_{km} - p_{km} \right) = x_{km} g + z_{km}. \tag{11}$$

Summing up, the parameters to be estimated are the bs, the gs, the a s, s_K and s_H. At this point, note that the pricing equation looks like a hedonic price equation that satisfies some behavioral and structural assumptions and constraints through the markup. In other terms, just considering a standard hedonic price equation for analyzing the pricing behavior in this differentiated-products market would certainly cause a misspecification.[30] Note also that the parameters of interest, i.e., the a s, s_K and s_H, could be estimated directly from the demand equation without the need of the pricing equation. Estimating these two equations together improves the quality of estimates of these parameters of interest.

Estimation method

The system formed by equations (9) and (11) contains several endogenous variables: price, shipment quantity, and shares of different nests. However, following the usual practice, we assume that the characteristics of PCs are exogenous, an assumption that allows us to identify the model. This is a strong assumption, as the choice by firms of characteristics for their computers might result from a strategic behavior in a dynamic setting. Here, the only characteristic we can use is the processor speed. It is fairly reasonable to assume that the technical progress on processors is a state variable for PC vendors.

A further aspect of this econometric model is that the error terms x and z may be correlated. In these conditions the nonlinear three-stage least-squares estimator is an adequate choice given the structure of the econometric model. For instance this estimator is easily implemented using the procedure MODEL of the software package SAS.[31]

This method requires choosing a set of instrumental variables. Given the variables available in our data set, this choice is very limited. This set contains all exogenous variables that enter the model and some functions of the variables linked to the characteristics of the home PC segment. For each country and time period, one defines, for a given brand, the following instruments: The total number of brands; the number of brands per vendor, the number of brands per form factor, the number

[29] Without loss of generality, we assume an identical set of exogenous variables for measuring the marginal cost and the deterministic component of the demand equation.
[30] For an analysis of hedonics, see Pakes [2001].
[31] We do not need to simplify the expression of the markup in Equation (7) in order to estimate the model, as Verboven [1996] proposed to proceed.

of brands per operating systems, the number of brands per type and speed of processors, the number of brands that a vendor sold with the same PC form factor, the number of brands that a vendor sold with the same operating system, and the number of brands that all the competitors of a vendor sold with the same form factor. This set of variables has been selected after a series of tries with different combinations of variables. Any departure from the set of selected variables ends up either with troubles for getting convergence of estimators or with meaningless results.

The choice of instruments has an effect on the specification of the model. Given the limited set of instruments, it was not possible to estimate the model with a different parameter a for each country. To retain the idea of a parameter that can vary across countries, this parameter is assumed to be a function of the Gross National Product per capita (in current USD), in each country in each year, according to:

$$a_m = a_0 + a_1 GNP_m \, , \tag{12}$$

where a_0 and a_1 are parameters to be estimated. In addition to providing a more flexible model, this specification introduces a kind of wealth effect. If GNP per capita is a proxy for wealth, one should expect a_1 to be negative. Richer countries might be expected to be less sensitive to PC prices.

Specification of the market size

Before proceeding to the estimation, a last task is to determine the potential market size N_m. A lower bound for this is obviously PC shipments to the home segment, which would imply that no consumers choose the outside good. When a household selects the outside good instead of buying a new computer, it means that either the household's members have decided to keep their old computer, or they have bought an electronic product like a handheld device or a network computer, or they have spent their money to something else. In these circumstances there is no obvious candidate for an upper bound for the potential market size. Even the total number of households in each country is not necessarily a suitable choice.

Consider Table 7. It provides the size of the installed base in each country based on data from the World Bank and the household PC shipments that we compute from the IDC database. Making different assumptions on the share of household PCs in the overall installed base, we end up with a ratio of shipments to the installed base for household PCs. (See columns 6-8 of Table 7.) Note that, according to IDC, households account for more than 50 percent of the installed base in the US. (See International Data Corporation [1998a].) The most useful evidence that can be drawn from Table 7 is that the computed ratios under each assumption are quite similar among countries.

We propose to measure the market size as follows. First, for each country and each year, we compute the average quarterly total shipments. Second, we inflate this number by a factor that we call the *potential market factor* t. (See Ivaldi and Verboven [2001].) According to the preceding discussion, we assert that realistic values for the potential market factor fall in the interval $[2,10]$. The value 2 corresponds roughly to the ratios given in column 8 of Table 7, and the value 10 to the ratios given in column 6. These are extreme values. Values in between these two extremes are probably realistic. This method permits us to obtain a potential market size that is country-specific, annually modified, and linked to the size of the installed base.

We report results for $t = 5.0$ and $t = 9.0$. It is important to point out that, in all our experiments, changing the value of the potential market factor does not drastically change our empirical results.

Parameter estimates

Table 8a presents the two sets of estimated values for the parameters of interest, corresponding to the two selected values of the potential market factor. Clearly the two sets are very similar. We may conclude that, provided we select a value for the potential market factor in the admissible range defined above, the parameter estimates should not be affected by this choice. From now on, the discussion is based on the results obtained when $t = 5.0$

Several other remarks on Table 8a are in order. First, all parameter estimates are significantly different from zero. Note that, as s_K and s_H are different from zero, the simple logit model is therefore rejected by the data. This means in particular that the home segment involves several levels of competition, across PC brands, across operating systems and across PC form factors and the outside good. Second as expected, a_1 is negative. By using the GNP per capita as a way to introduce country-dependent effects of PC prices on demand, we have identified a wealth effect. Third, these effects of price on demand are always negative for all countries, because the parameter a_m defined by Equation (12), is always positive. Fourth, the parameter s_K is greater than s_H, which is required for the model to be consistent with utility maximization. We conclude that our estimates are consistent with economic theory.[32]

Table 8b presents the other parameter estimates $t = 5.0$.[33] Most of these are coefficients for dummy variables; that they tend to differ significantly from zero implies that substantial differences in demand and cost exist across countries, form factors, and so forth. The general pattern of the estimates seems sensible. First, for example, both consumer utility and marginal cost rise with increases in the processor speed (for both Intel-compatible and Motorola/PowerPC processors). Second, a desktop has a lower marginal cost than a laptop or a small portable but provides a higher level of utility. Third,

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[32] As mentioned above, two different orderings for the consumer decision seem theoretically plausible. The estimates presented here start with choice of form factor, then choice of platform. Changing the ordering of these two choices leads to parameter values that are outside the admissible range and thus, to rejection of this alternative model. We have no explanation as why.

[33] Results from other experiments are available upon request.

while the type of client operating system has no significant effect on marginal cost of PCs, DOS/WIN provides a net utility gain. Note that one could interpret this parameter associated with the type of platform as a measure of the individual valuation of a membership of the DOS/WIN network.

Concerning the time variable, note that the quarterly effect seems realistic. Demand in higher in Winter probably due to the Christmas period; costs are lower in Winter because one could expect that more low-end machines are sold for Christmas. With respect to the annual effect, marginal costs are decreasing over time, which could indicate that we have identified an effect of technical progress on production costs, while the decreasing time effect over years on utility levels could be interpreted as an effect of satiation of demand. This last statement merits further comments.

We observe that the equipment rate in PCs, which measures the importance of the installed base, is strongly trended, the trend being country specific. We conjecture that the combination of the time and country dummies is a proxy for the effect of the installed base of PCs in each country.[34] Then the decreasing time effect over years on utility levels could be due to the a decreasing direct network effect of the installed base. Note however that, given that we do not take into account in our model how the installed base is affected in turn by the supply and pricing decisions of firms, the model is not able to identify the effect of such network effects. This is an open issue.

Concerning the country and firm effects, they are not straightforwardly interpretable. Note however the significant presence of a specific dummy variable, named "Others," that stands for an *ad hoc* aggregation of small firms not individually identified in the data. Finally cross effects between countries and vendors often differ from zero, a sensible result. Adding further cross effects either does not improve significantly the goodness-of-fit of the model, does not modify the estimates of parameters of interest or leads to convergence problems.

Elasticities and markups at the brand and firm levels

Estimated own- and cross-price elasticities as well as markups for some particular brands are presented in Table 9, and some statistics on the overall distribution of these estimated elasticities and markups at the brand level are provided in Table 10. Table 11 presents the estimated values of aggregate elasticities at the firm level, for some of the major vendors. These latter elasticities are calculated as the percent change in shipments of all products sold by a firm when the prices of all these products are increased by one percent. Before discussing these elasticities and markups, it is useful to return on Table 8a and to assess the values taken by the parameters of interest, in particular s_K and s_H. Indeed, these parameters play a crucial role in the formulas given in Appendix B for computing the different types of elasticity.

[34] Coherent series for the equipment rate are obtained from the World Bank Web site where it is measured as the number of PCs per 1000 inhabitants. See Table 7.

First, because s_K is significant and close to (although statistically different from) one, PC brands are almost perfect substitutes, which is a realistic result. It means that individual preferences are correlated across PCs within the same group defined by the type of operating system and that one may expect a fierce competition between PCs belonging to the same platform type. It is exactly what the estimated values of elasticities tell us, in particular when one looks at the cross elasticities among products sharing the same form and the same OS. (See in particular the second row of Table 10 or the cross elasticity between the Compaq Presario and the Dell Dimension in Table 9.)

Second, because s_H is significantly different from zero and is not close to s_K, preferences are correlated across PCs of different platforms, but this correlation is much weaker than across PCs within a platform. This fact is reflected in the values taken by the estimated cross elasticities displayed in Tables 8 and 9.

Finally, consider the estimated own-price elasticities and markups at the brand level and look at the aggregate elasticities at the firm level. (See Table 11.) We observe that the price elasticities (markups, respectively) are quite high (low) for all PCs based on the DOS/WIN platform and are much smaller (higher) for PCs based on the MacOS platform.[35] These results indicate that the home segment of the PC manufacturing industry is highly competitive.

However one may deem that the own-price elasticities at the brand level are too high. The features of the nested-logit model may explain these results. This model amplifies the phenomena: On the one side any DOS/WIN PC has a rather small markup while on the other side, any MacOS PC has a very high markup. This result must be related to the structure of the decision tree in our model: On one branch we have a lot of firms in competition, on the other branch there is basically one firm producing all the brands. Our nested-logit model is not flexible enough to smooth this situation.[36] Nonetheless our results are not counterintuitive. Note that the home segment is probably more competitive than the business segment for instance. A PC is a durable good for a household, i.e., a commodity that is bought once for a “long period.” In this condition any price change on a brand at a given time could have a strong and rapid effect on the sales of this brand, particularly when plenty of substitutes are present on the shelves of distributors.

Aggregate elasticity of PCs

Table 12 provides our estimates of the elasticity of the aggregate demand of household PCs, for all the G7 countries for different periods and values of the potential market factor. The aggregate

[35] Note that markups, obtained from an economic model and here computed according to Equation (7), should not be compared to markups obtained from accounting data.
[36] This appraisal on our nested-logit model should be related to other critical assessments of this type of models. See for instance Hausman and Leonard [1997] and Slade [2001].

elasticity is calculated as the percentage change in total shipment due to a one-percent increase in the price of all products on the market. We also provide estimates of the aggregate demand elasticity when only PCs based on the DOS/WIN platform are considered, i.e., when prices of all such computers rise by 1 percent while the prices of Macintosh and other computers remains unchanged. This elasticity is also the one of the aggregate demand of the DOS/WIN platform.

Our estimates of the aggregate demand elasticity for year 1999 takes values around 1.7, with the lowest value for the US, namely 1.66, and the highest value for Japan, 1.85. The elasticities for DOS/WIN PCs alone are in general slightly higher, with the 1999 elasticities 2.01 for the US and 2.30 for Japan. Given that the demand of OS is a derived demand, these numbers seem fairly reasonable and realistic.

V. COUNTERFACTUALS

We use our estimated model of the home PC segment to estimate the price elasticity of operating systems and to derive implications for the price of such software. We focus our attention on the price of DOS/WIN systems. One limitation of our approach is that our analysis of the monopoly price of Windows is based only on the home segment. To our knowledge, Microsoft cannot readily price discriminate between copies of Windows installed on PCs used for the home segment and other segments. As a result, if the price elasticity of demand for the home segment is larger than the aggregate price elasticity of demand across all segments, we are likely to understate the monopoly price of Windows.

Two situations are considered. First, assuming that computer manufacturers passed on exactly 100 percent of all price increases for DOS/WIN, we look for the unilateral static monopoly price of DOS/WIN. Second, we solve the Nash equilibrium model where the seller of DOS/WIN is maximizing its profit assuming that buyers of DOS/WIN, who are sellers of PCs, are choosing their best strategy. In this second case, we refer to the Nash monopoly price of DOS/WIN.

Unilateral monopoly price

Let C^W be the set of products equipped with the operating system DOS/WIN and C^A be the set of products equipped with the operating system MacOS. The model provides the demand for personal computer *k*,

$$q_k = q_k\left(p^w, p^A\right), \quad \forall k \in C^w \cup C^A, \tag{13}$$

where p^w is the price vector of PCs equipped with DOS/WIN and p^A is the price vector of PCs equipped with MacOS. Define $\overline{p}_k^w$ as the prices of the PC *k* powered with an Intel processor but without the operating system installed, and p_w as the price of DOS/WIN. Then

$$\overline{p}_k^w = p_k^w - p_w, \tag{14}$$

for some base levels of prices for PC *k*, p_k^w, and for DOS/WIN. For our calculations related to the unilateral monopoly price, we assume that $\overline{p}_k^w$ is fixed and that the price of system *k* will rise dollar for dollar with increases in the price of DOS/WIN. This assumption is not perfectly consistent with the assumption in our pricing equation, which is an equilibrium condition, but it provides a simple way to calculate approximate monopoly price. This price p_w is assumed to be constant across computer vendors, which is not the case for large vendors that get volume discounts.[37] We return on this point later. Now the demand of DOS/WIN is obtained as

$$q_w = \sum_{k \in C^w} q_k, \tag{15}$$

and the price elasticity is

$$e^W \equiv \left(\sum_{k \in C^w} \frac{\partial q_k}{\partial p_w} \right) \frac{p_w}{q_w} = \left(\sum_{k \in C^w} \sum_{k' \in C^w} \frac{\partial q_k}{\partial p_{k'}^w} \right) \frac{p_w}{q_w}. \tag{16}$$

The second part of this last equation is obtained by applying the implicit function theorem. An increase in the price of operating systems causes a decrease in the demand for product *k* through the rise of the price of product *k* everything being equal. However it also increases the prices of competing brands, which push up the demand for product *k*. The result of this process is not trivial.

When the seller of the client operating system DOS/WIN is maximizing its profit taking the non-OS component of the prices of PCs ($\overline{p}_k^w$) as constant, it must choose the price p_w^* that satisfies

$$\frac{p_w^* - c_w}{p_w^*} = -\left[\left(\sum_{k \in C^w} \sum_{k' \in C^w} \left. \frac{\partial q_k^w}{\partial p_{k'}^w} \right|_{p_w^*} \right) \left. \frac{p_w}{q_w} \right|_{p_w^*} \right]^{-1}, \tag{17}$$

where c_w is the marginal cost of producing DOS/WIN. This price corresponds to the monopoly price assuming that vendors are selecting their best strategy. The OS seller acts here very much in the same way as the leader in the first step of a Stackelberg equilibrium.

[37] Large vendors enter in contractual relationships with Microsoft. These contracts involves nonlinear pricing schemes which are unknown to us. The effects of these schemes are hard to predict.

Equation (17) must be solved numerically. In the simulation experiments below, we assume that the marginal cost of producing DOS/WIN is zero. In this case, Equation (17) just tells us that, for maximizing profit, the optimal decision is to price at the point where the aggregate elasticity of demand is unity. Table 13 gathers the simulated unilateral monopoly prices that we obtain for the G7 countries and for some typical time periods using the model estimated previously.[38] On average, for year 1999, the lowest value is $575 for France and the highest value is $622 for Japan. These values are around ten times the actual price of DOS/WIN (around $60), and three times the sum of the actual DOS/WIN price and the average price of Microsoft's DOS/WIN applications (around $200) that it can expect to sell as complements when it sells an extra copy of DOS/WIN.[39]

These estimates are below the profit-maximizing price of Windows, namely $900, derived by Reddy, Evans and Nichols [1999] in the context of a model of perfectly competitive PC suppliers. Werden [2001a] explains the high estimate found by Reddy et al. as a direct result of the unrealistic assumption of homogeneity of PCs made by these authors. He shows that, in a model with heterogeneous products and assuming plausible values for some market parameters, the present price of Windows turns out to be the profit-maximizing price.[40] On the one side, our results seem to confirm the Werden's conjecture in the sense that our model accounts for the high degree of differentiation of PC products. On the other side, they also show that, with a differentiated-products model estimated on actual data, the profit-maximizing price is still much higher than the present price of DOS/WIN.[41]

Nash monopoly price

Instead of assuming that the producer of DOS/WIN is taking the non-OS component of the prices of PCs as given, we consider it as a player in a Nash equilibrium where the other players are the vendors of PCs. The program of the OS producer is

$$\underset{p_w}{Max}\left(p_w - c_w\right)\sum_{k \in C^w} q_k = \left(p_w - c_w\right) q_w \,. \tag{18}$$

As before the PC vendors have the same program defined by Equation (6). Note that the prices of PCs still satisfy Equation (14).[42] The set of first-order conditions associated with Equation (18) and Equation (6) must be solved numerically.

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38 Of course, prices of PCs increase. Given the small margins we have found, it is not surprising that these increases are roughly in the order of magnitude of the increase in the price of DOS/WIN. That is to say, the passthrough is here also almost total.

39 Taking into account these complementary revenues is equivalent to assuming negative marginal costs for producing DOS/WIN. Note that any change in the value of the marginal cost for producing DOS/WIN is almost completely incorporated in the price of DOS/WIN.

40 Werden's conjecture has initiated an exchange of replies between Reddy *et al.* [2001 a and b] and Werden [2001b].

41 Note also that Werden (in his examples) and Reddy *et al.* use demands with constant elasticities, which is not the case here.

42 In other terms, contrary to the case of the unilateral monopoly price, the price of system *k* do not rise dollar for dollar with increases in the price of DOS/WIN. In general the passthrough is partial.

Table 13 is completed with the values of DOS/WIN price that result from solving these equations using the estimated model. For the set of products present on the market in 1999, the Nash monopoly price is around 600 US dollars. It is slightly lower than the monopoly price because the Nash equilibrium accounts for the fact that vendors and OS producers interact.

On the determination of actual prices

These results show that the actual price of DOS/WIN (around $60) is much lower than the prices obtained under standard equilibrium concepts. One reason could be that the DOS/WIN price is chosen from a different program. Assume for instance that, instead of maximizing profits, the program is to maximize a linear combination of the ratio of actual income to the expected income under the Nash equilibrium and of the market share, i.e.,

$$\operatorname*{Max}_{p_w} d\, \frac{p_w q_w}{R_w^N} + (1-d)\frac{q_w}{N}, \tag{19}$$

where R_w^N is the income that the DOS/WIN producer could realize by applying the Nash monopoly price. This objective function may reflect a trade-off between present and future profits.[43] The normalization, which is necessary for obtaining commensurable terms in the objective function, is debatable. Instead of R_w^N one could use the total amount of profits in the industry, i.e., the sum of the profits of the DOS/WIN producer, the profits of the MacOS producer and the profits of producers of different substitutes. Our choice has the advantage of reflecting what may well concern a firm like Microsoft: Balancing current profits against a need to generate substantial future network externalities in order to produce future profits.

Now the problem is to find the value of d so that the solution to Equation (19) corresponds to the actual price of DOS/WIN, i.e., roughly $60. On average for year 1999, the numerical analysis produces the results gathered in Table 14. The value of d is between 6.2 and 9.5 percent, indicating that the DOS/WIN producer is giving vastly more weights to the future. Two conclusions can be drawn from this result. First, we obtain a value that falls in the unit interval, which means that there are no inconsistencies in our estimated model. Second, a dynamic analysis of the working of the industry, perhaps along the lines suggested by Fudenberg and Tirole [2000], is urgently needed.

VI. CONCLUSION

By fitting a simple equilibrium model of the home PC market on a large data set covering the major industrial countries over a significant period of time, we provide evidence that the static profit-

[43] As Fudenberg and Tirole [2000] have pointed out, a monopolist in a dynamic market with network externalities faces tradeoffs because maximizing current profits will reduce the future network externalities and therefore future profits.

maximizing price of Windows under monopoly might be much higher than the observed price (even if one accounts for the price of Microsoft's complementary products). This result is in part driven by the relatively low aggregate elasticity of demand for PCs, and so for operating systems since PCs and OSs are shipped in fixed proportions. Note however that, if the price elasticity of demand for the home segment is larger than the aggregate price elasticity of demand across all other segments, we are likely to understate the monopoly price of Windows. Nonetheless, the empirical analysis supports the view that the rules governing derived demand that we mention in the introduction of this article are satisfied in our case.

As with all empirical work, these results are based on numerous assumptions. Among them the nested-logit model used to specify the demand side plays a crucial role. Other specifications of the demand side could have been used at a higher cost of complexity or computation.[44] The nested-logit model has three advantages. First, it remains parsimonious in the number of parameters, while it accounts for the very high degree of differentiation on the market under investigation. Second it is easy to implement and to estimate. Third, it provides a useful benchmark for applying economic policy, as we illustrate with the case of PCs.[45] The nested-logit model assumes that a decision tree, with a hierarchical structure with nests and branches, represents consumer preferences. Its main feature is imposing symmetric substitution patterns within a nest, while allowing for asymmetric substitution patterns across nests. That PCs within the same form factor and platform are symmetric substitutes does not seem to be a too unrealistic assumption. They could be closer substitutes, in which case one could expect smaller elasticities at the brand level and so a smaller aggregate elasticity of demand for PCs (everything being equal). In other terms using an approach based on the nested-logit approach would lead to underestimate the profit-maximizing price of Windows, i.e., would be conservative.

Effects of other assumptions like the Nash assumption or the constancy of the price of operating systems across computer vendors are much harder to assess. However, the main drawback of our model is that it ignores network effects and the dynamic aspects of competition. Indeed we have shown that, if Microsoft's objective was to maximize a weighted sum of its present profit and its market share, it would place a much higher weight on the latter than the former. Microsoft seems to behave as if it fears that charging monopoly prices today would cause it to loose substantial profits to competitors in the future. This indicates that a dynamic framework is needed for decoding empirically the forces driving the price of software systems. This framework could be found in the theoretical perspective recently developed by Fudenberg and Tirole [2000] where the role of operating systems as network goods is fully recognized.

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[44] An alternative approach which explicitly allows for overlapping nests is proposed by Bresnahan, Stern and Trajtenberg [1997]. It is still parsimonious, albeit more computationally intensive.

[45] It is a related set of reasons that explains the use of logit models in merger analysis. (See Werden and Froeb [1994], Ivaldi and Verboven [2000].)

APPENDIX A: THE DEMAND SYSTEM

Given the specification of the random indirect utility function provided by equations (1)-(3) and the assumptions made on the error terms, one can use the well known properties of the nested logit model to derive the following conditional probabilities.

The probability of choosing brand *k* conditional to the choice of nest (h,g) defined by a particular operating system and a specific PC form is

$$s(k|h,g) = \frac{\exp\left(m_K V_{k(h,g)}\right)}{\sum_{k' \in K_{hg}} \exp\left(m_K V_{k'(h,g)}\right)}, \tag{A.1}$$

where $m_K = 1/(1 - s_K)$. The conditional probability of choosing the operating system *h* conditional to the choice of form *g* is

$$s(h|g) = \frac{\exp\left(m_H V_{h(g)}\right)}{\sum_{h' \in H_g} \exp\left(m_H V_{h'(g)}\right)}, \tag{A.2}$$

where $V_{h(g)}$ is the inclusive value defined as

$$V_{h(g)} = m_K^{-1} \ln \sum_{k \in K_{hg}} \exp\left(m_K V_{k(h,g)}\right) \equiv m_K^{-1} \ln D\left(K_{hg}\right). \tag{A.3}$$

Finally the probability of choosing the form *g* is

$$s(g) = \frac{\exp\left(V_g\right)}{\sum_{g \in G} \exp\left(V_g\right)}, \tag{A.4}$$

where V_g is the inclusive value defined as

$$V_g = m_H^{-1} \ln \sum_{h \in H_g} \exp\left(m_H V_{h(g)}\right) = m_H^{-1} \ln D\left(H_g\right). \tag{A.5}$$

Note that the utility associated with the outside good is normalized so that $V_O = 0$ and $s(O) \equiv s_O = \left(\sum_{g \in G} \exp\left(V_g\right)\right)^{-1} = D(G)^{-1}$.

The unconditional probability of selecting product *k* is obtained as the product

$$s_k = s(k|h,g)\, s(h|g)\, s(g), \tag{A.6}$$

i.e., in a more developed form,

$$s_k = \frac{\exp\left(m_K V_{k(h,g)}\right)}{D\left(K_{hg}\right)} \frac{D\left(K_{hg}\right)^{(m_H/m_K)}}{D\left(H_g\right)} \frac{D\left(H_g\right)^{(1/m_H)}}{D(G)}. \tag{A.7}$$

Using the logarithmic form and the definitions above yields

$$\ln s_k = m_K V_{k(h,g)} + \left(\frac{m_H}{m_K} - 1\right) \ln D\left(K_{hg}\right) + \left(\frac{1}{m_H} - 1\right) \ln D\left(H_g\right) + \ln s_O. \tag{A.8}$$

As $\ln D\left(K_{hg}\right) = m_K V_{k(h,g)} - \ln s(k|h,g)$, $\ln D\left(H_g\right) = m_H V_{h(g)} - \ln s(h|g)$, and $V_{h(g)} = V_{k(h,g)} - m_K^{-1} \ln s(k|h,g)$, rearranging equation (A.8) accordingly generates

$$\ln s_k = V_{k(h,g)} + s_K \ln s(k|h,g) + s_H \ln s(h|g) + \ln s_0, \tag{A.9}$$

which is basically Equation (4) given in the text. All probabilities must be interpreted as market shares.

APPENDIX B: DEMAND ELASTICITY

From equation (A.8) and using the features of the logit model, one can easily derive the different types of demand elasticity. The following expressions hold:

i) Own-elasticity:

$$\frac{\partial \ln q_k}{\partial \ln p_k} = a\, q_k \left[-\frac{1}{1-s_K} + q_k r_{hg} \right] \frac{p_k}{q_k}, \quad \forall k \in K_{hg} \,. \tag{B.1}$$

ii) Cross-elasticity within the same group g and the same sub-group h:

$$\frac{\partial \ln q_k}{\partial \ln p_j} = a\, q_j q_k r_{hg} \frac{p_j}{q_k}, \quad \forall j,k \in K_{hg}\,,\ j \neq k \,. \tag{B.2}$$

iii) Cross-elasticity within the same group g and between different sub-groups h:

$$\frac{\partial \ln q_k}{\partial \ln p_j} = a\, q_j q_k r_g \frac{p_j}{q_k}, \quad \forall k \in K_{hg}, \forall j \in K_{h'g}, h \neq h' \,. \tag{B.3}$$

iv) Cross-elasticity between different groups g:

$$\frac{\partial \ln q_k}{\partial \ln p_j} = a\, q_j q_k r_0 \frac{p_j}{q_k}, \quad \forall k \in K_{hg}, \forall j \in K_{h'g'}, h \in H_g, h' \in H_{g'}, g \neq g' \,. \tag{B.4}$$

Note that r_0, r_g and r_{hg} are defined in Equation (8).

APPENDIX C: THE GENERIC FIRM'S PROGRAM

The profit-maximizing firm *f* solves, for each product *k*, the following first-order condition:

$$q_k + \frac{\partial q_k}{\partial p_k}(p_k - c_k) + \sum_{\substack{j \in S^f \\ j \neq k}} \frac{\partial q_j}{\partial p_k}(p_j - c_j) = 0 \qquad \text{(C.1)}$$

where S^f is the set of products shipped by firm *f*. Without loss of generality we drop index *f* in the sequel. Nonetheless recall that all set of products are defined with respect to the own set of product of the firm. For instance, here K_{hg} is the subset of products of firm *f* that belongs to the nest (h,g).

Using the expressions of the four types of demand elasticity, Equation (C.1) can be restated as

$$\begin{aligned} & q_k - a\,q_k \frac{1}{1-s_K}(p_k - c_k) + a\,q_k r_{hg} \sum_{j \in K_{hg}} q_j (p_j - c_j) \\ & \quad + a\,q_k r_g \sum_{h' \in H_g - \{h\}} \sum_{j \in K_{h'g}} q_j (p_j - c_j) + a\,q_k r_0 \sum_{g' \in G - \{g\}} \sum_{h \in H_{g'}} \sum_{j \in K_{hg'}} q_j (p_j - c_j) = 0. \end{aligned} \qquad \text{(C.2)}$$

or

$$\begin{aligned} & \frac{1}{a} - \frac{1}{1-s_K}(p_k - c_k) + r_{hg} \sum_{j \in K_{hg}} q_j (p_j - c_j) \\ & \quad + r_g \sum_{h' \in H_g - \{h\}} \sum_{j \in K_{h'g}} q_j (p_j - c_j) + r_0 \sum_{g' \in G - \{g\}} \sum_{h \in H_{g'}} \sum_{j \in K_{hg'}} q_j (p_j - c_j) = 0. \end{aligned} \qquad \text{(C.3)}$$

i) Step 1: Write Equation (C.3) for product k' that belongs to the same nest as product *k*. It is direct to check that

$$(p_k - c_k) = (p_{k'} - c_{k'}), \quad \forall k, k' \in K_{hg}. \qquad \text{(C.4)}$$

Then Equation (C.3) can be rewritten

$$\begin{aligned} & \frac{1}{a} - \frac{1}{1-s_K}(p_k - c_k) + r_{hg}(p_k - c_k) Q_{hg}^f \\ & \quad + r_g \sum_{h' \in H_g - \{h\}} \sum_{j \in K_{h'g}} q_j (p_j - c_j) + r_0 \sum_{g' \in G - \{g\}} \sum_{h \in H_{g'}} \sum_{j \in K_{hg'}} q_j (p_j - c_j) = 0. \end{aligned} \qquad \text{(C.5)}$$

where $Q_{hg}^f = \sum_{j \in K_{hg}} q_j$ is the quantity of the different brands belonging to the same nest and produced by firm *f*.

ii) Step 2: Now let us simplify the term $\sum_{h' \in H_g - \{h\}} \sum_{j \in K_{h'g}} q_j (p_j - c_j)$. Consider product $l \in K_{h'g}$ with $h' \in H_g - \{h\}$. One writes Equation (C.5) for this product and one reintroduces product *k*. One obtains easily:

$$\begin{aligned} & \frac{1}{a} - \frac{1}{1-s_K}(p_l - c_l) + r_{h'g}(p_l - c_l) Q_{h'g}^f \\ & \quad + r_g \left[(p_k - c_k) Q_{hg}^f + \sum_{h'' \in H_g - \{h, h'\}} \sum_{j \in K_{h''g}} q_j (p_j - c_j) \right] \\ & \quad + r_0 \sum_{g' \in G - \{g\}} \sum_{h \in H_{g'}} \sum_{j \in K_{hg'}} q_j (p_j - c_j) = 0. \end{aligned} \qquad \text{(C.6)}$$

Permuting *k* and l in Equation (C.6) yields:

$$\frac{1}{a}-\frac{1}{1-s_K}(p_k-c_k)+r_{hg}(p_k-c_k)Q^f_{hg} + r_g\left[(p_l-c_l)Q^f_{h'g}+\sum_{h''\in H_g-\{h,h'\}}\sum_{j\in K_{h''g}}q_j\left(p_j-c_j\right)\right] + r_0\sum_{g'\in G-\{g\}}\sum_{h\in H_{g'}}\sum_{j\in K_{hg'}}q_j\left(p_j-c_j\right)=0. \tag{C.7}$$

Then subtracting Equation (C.7) from Equation (C.6) and simplifying provides

$$(p_l-c_l)=\frac{\Gamma_{hg}}{\Gamma_{h'g}}(p_k-c_k), \tag{C.8}$$

where Γ_{hg} is defined in the text. Plugging Equation (C.8) into Equation (C.5) one obtains

$$\frac{1}{a}-\frac{1}{1-s_K}(p_k-c_k)+r_{hg}(p_k-c_k)Q^f_{hg} + r_g\Gamma_{hg}(p_k-c_k)\sum_{h'\in H_g-\{h\}}\frac{Q^f_{h'g}}{\Gamma_{h'g}}+r_0\sum_{g'\in G-\{g\}}\sum_{h\in H_{g'}}\sum_{j\in K_{hg'}}q_j\left(p_j-c_j\right)=0. \tag{C.9}$$

iii) Step 3: Finally one applies a similar change to the term $\sum_{g'\in G-\{g\}}\sum_{h\in H_{g'}}\sum_{j\in K_{hg'}}q_j\left(p_j-c_j\right)$ in Equation (C.9). Consider product $l\in K_{hg'}$ with $h\in H_{g'}$ and $g'\in G-\{g\}$. Replacing *k* by *l* in Equation (C.9) one obtains the first order condition for product *l*, taking care of reintroducing product *k* in the term under investigation, i.e.,

$$\frac{1}{a}-\frac{1}{1-s_K}(p_l-c_l)+r_{hg'}(p_l-c_l)Q^f_{hg'} + r_{g'}\Gamma_{hg'}(p_l-c_l)\sum_{h'\in H_{g'}-\{h\}}\frac{Q^f_{h'g'}}{\Gamma_{h'g'}} + r_0\left[(p_k-c_k)Q^f_{hg}+\Gamma_{hg}(p_k-c_k)\sum_{h'\in H_g-\{h\}}\frac{Q^f_{h'g}}{\Gamma_{h'g}}+\sum_{g''\in G-\{g,g'\}}\sum_{h\in H_{g''}}\sum_{j\in K_{hg''}}q_j\left(p_j-c_j\right)\right]=0. \tag{C.10}$$

Permuting *k* and *l* in Equation (C.10) gives

$$\frac{1}{a}-\frac{1}{1-s_K}(p_k-c_k)+r_{hg}(p_k-c_k)Q^f_{hg} + r_g\Gamma_{hg}(p_k-c_k)\sum_{h'\in H_g-\{h\}}\frac{Q^f_{h'g}}{\Gamma_{h'g}} + r_0\left[(p_l-c_l)Q^f_{hg'}+\Gamma_{hg'}(p_l-c_l)\sum_{h'\in H_{g'}-\{h\}}\frac{Q^f_{h'g'}}{\Gamma_{h'g'}}+\sum_{g''\in G-\{g,g'\}}\sum_{h\in H_{g''}}\sum_{j\in K_{hg''}}q_j\left(p_j-c_j\right)\right]=0. \tag{C.11}$$

Then subtracting Equation (C.11) from Equation (C.10) and simplifying yields

$$(p_l-c_l)=\frac{\Lambda_{hg}}{\Lambda_{hg'}}(p_k-c_k), \tag{C.12}$$

where Λ_{hg} is defined in the text. Plugging Equation (C.12) into Equation (C.9) one obtains

$$\frac{1}{a}-\frac{1}{1-s_{K}}\left(p_k-c_k\right)+r_{hg}\left(p_k-c_k\right)Q_{hg}^{f} + r_g\Gamma_{hg}\left(p_k-c_k\right)\sum_{h'\in H_g-\{h\}}\frac{Q_{h'g}^{f}}{\Gamma_{h'g}} + r_0\Lambda_{hg}\left(p_k-c_k\right)\sum_{g'\in G-\{g\}}\sum_{h\in H_{g'}}\frac{Q_{hg'}^{f}}{\Lambda_{hg'}}=0. \tag{C.13}$$

Finally rearranging Equation (C.13) provides the expression of the markup defined as

$$\left(p_k-c_k\right)=\frac{1}{a}\left[\frac{1}{1-s_{K}}-r_{hg}Q_{hg}^{f}-r_g\Gamma_{hg}\sum_{h'\in H_g-\{h\}}\frac{Q_{h'g}^{f}}{\Gamma_{h'g}}-r_0\Lambda_{hg}\sum_{g'\in G-\{g\}}\sum_{h\in H_{g'}}\frac{Q_{hg'}^{f}}{\Lambda_{hg'}}\right]^{-1}. \tag{C.14}$$

Figure 1: Average market shares by platform type and country

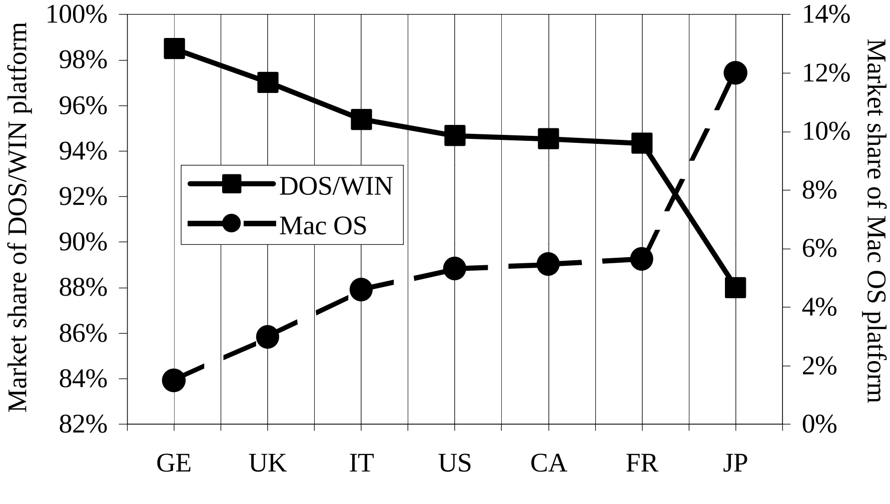

Table 1: Average market shares by country for firms in top 10 in at least two countries

	Canada	France	Germany	Italy	Japan	UK	US
Acer	1.09	2.39		3.27			2.35
Apple	4.92	5.26		4.37	11.39	2.77	5.06
AST	2.78			2.02			
Compaq	10.77	7.43	3.64	6.37	2.90	6.43	13.46
Dell	3.17					4.39	3.19
Fujitsu		4.73	15.89		20.11	3.81	
Gateway					2.39	2.87	10.27
Hewlett-Packard	5.04	3.81					7.45
IBM	12.84	6.60		4.99	9.30	3.45	5.32
NEC/PackardBell	7.31	17.59	2.32	7.18	29.42	19.55	14.93
Toshiba	2.99				4.23		1.50
Vobis			24.05	6.04			
Other top-10	46.67	40.96	39.58	58.59	14.74	32.87	29.42
Others	2.40	11.22	14.52	7.18	5.53	23.87	7.02
All vendors	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Note: Only vendors that appear in the top 10 vendors of at least two different countries are reported. The category "Other top-10" refers to vendors that are in the top 10 in only one country. The average shares are computed over the sample period 1995 – 1999. Figures are percentages.

Table 2: PC shipments and market shares by top-10 vendors per year over the G7 countries

	1995		1996		1997		1998		1999	
	Share	Shipment (000)	Share	Shipment (000)	Share	Shipment (000)	Share	Shipment (000)	Share	Shipment (000)
Acer	2.75	417	2.82	466	2.39	417				
Apple	9.86	1495	6.49	1074	3.13	547	4.19	842	4.97	1452
AST	1.97	299	2.21	365						
Compaq	6.03	915	8.68	1435	10.62	1856	10.48	2105	12.40	3620
Dell							2.87	576	4.04	1179
Emachines									4.79	1400
ESCOM	2.06	313								
Fujitsu	2.55	387	4.84	801	4.76	831	5.63	1130	5.45	1592
Gateway	4.40	668	4.52	748	6.80	1188	8.50	1706	8.36	2440
Hewlett-Packard					3.35	585	6.87	1380	8.41	2455
IBM	6.33	961	6.33	1046	5.33	931	6.11	1227	5.21	1521
NEC/PackardBell	22.94	3481	20.96	3466	18.71	3271	13.80	2771	9.02	2633
Sony							2.22	445	3.20	934
Toshiba			2.98	492	2.56	448				
Vobis	3.29	499	3.47	574	2.80	489	2.14	430		
Others	37.81	5736	36.69	6067	39.57	6918	37.20	7471	34.16	9977
All vendors	100.00	15170	100.00	16533	100.00	17482	100.00	20084	100.00	29204

Note: Only the shares (in percent) of the top 10 vendors are reported for each year.

Table 3: Statistics on the distribution of market shares at brand level per year and country

	1995			1997			1999		
	Max	Mean	St Dev	Max	Mean	St Dev	Max	Mean	St Dev
Canada	8.82	0.28	0.80	8.40	0.21	0.72	7.39	0.32	0.92
France	16.73	0.19	0.97	12.44	0.15	0.71	4.57	0.10	0.34
Germany	4.87	0.23	0.53	4.22	0.21	0.52	3.61	0.09	0.26
Italy	12.39	0.25	0.97	11.04	0.23	0.83	12.38	0.12	0.55
Japan	11.84	0.26	0.79	3.54	0.13	0.35	2.90	0.15	0.36
UK	4.43	0.14	0.38	10.02	0.13	0.48	4.23	0.10	0.33
US	4.59	0.16	0.49	3.07	0.11	0.33	3.35	0.12	0.37
G7	16.73	0.28		12.44	0.23		12.38	0.32	

Note: Figures are percentages.

Table 4: Average number of brands and Intel-compatible processor types per year and country

	1995		1997		1999		Mean	
	Brand	Processor	Brand	Processor	Brand	Processor	Brand	Processor
Canada	51	4	53	5	35	10	51	6
France	76	4	82	5	110	9	87	5
Germany	63	4	59	5	111	8	79	5
Italy	58	3	54	5	93	8	69	5
Japan	48	4	75	5	68	9	71	5
UK	77	4	99	5	105	9	95	5
US	79	4	104	5	117	10	103	6
Mean	65	4	75	5	91	9	79	5

Note: This counts each brand, regarding the speed of processors, and each processor, regarding the brands.

Table 5: Distribution of shipments by generation of Intel-compatible processors (G7 countries)

Intel processor type	1995	1996	1997	1998	1999
486+Below	35.14	9.07	0.37		
5th Gen. 100 MHz+Below	36.43	24.07	5.26	0.09	
5th Gen. 101-149 MHz	25.73	29.65	20.74	3.44	0.30
5th Gen. 150-179 MHz	1.80	19.23	27.99	14.07	2.45
5th Gen. 180 MHz+Above	0.42	6.74	19.54	22.67	6.40
6th Gen. <=200 MHz	0.49	11.23	12.30	1.22	0.01
6th Gen. 201-299 MHz			11.99	27.01	19.01
6th Gen. 300-399 MHz			1.81	20.07	28.85
6th Gen. 400-499 MHz				11.43	27.41
6th Gen. 500-599 MHz					12.78
6th Gen. 600-699 MHz					2.46
6th Gen. 700-799 MHz					0.31

Table 6: Statistics on the PC prices per year and country

	1995		1996		1997		1998		1999	
	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev
Canada	2331	996	2114	756	2047	647	1849	711	1900	891
France	2040	588	2014	717	1896	939	1798	855	1626	604
Germany	1912	759	2094	1106	1860	785	1983	857	1785	603
Italy	1661	550	1659	553	1494	516	1567	666	1490	506
Japan	2558	928	2959	1159	2455	844	2150	792	2086	663
UK	2402	956	2396	967	2037	763	2084	942	1755	771
US	2530	680	2499	669	2310	671	2198	737	1841	696
Mean	2205		2248		2014		1947		1783	

Note : Units are current USD.

Table 7: Evaluation of the average market size of the home PC segment over period 1995-1999

					Share of Household PCs in actual installed base		
					100%	50%	20%
	Number of PC per head	Population size	Installed base	Household PC shipments	Household PC shipments to installed base ratio		
Canada	266.85	29988400	7975550	643297	7.20	14.40	35.99
France	166.37	58610100	9738329	968571	8.48	16.96	42.41
Germany	246.06	81939800	20162444	1775548	8.47	16.94	42.34
Italy	115.63	57468980	6644267	434784	6.21	12.41	31.04
Japan	180.41	126054200	22733388	2809602	10.49	20.97	52.43
UK	230.89	58916400	13595972	1241258	8.16	16.33	40.82
US	389.38	267775200	103905023	11821712	10.11	20.22	50.54

Note: All the figures are average over the period 1995-1999. Sources: World Bank and IDC.

Table 8a: Estimates of parameters of interest

	Potential market factor			
	$t = 5.0$		$t = 9.0$	
Parameter name	Estimate	T-Ratio	Estimate	T-Ratio
a_0	18.881	30.8	18.788	31.0
a_1	-0.226	-2.3	-0.219	-2.2
s_K	0.943	107.0	0.942	107.7
s_H	0.230	2.3	0.228	2.3

Table 8b: Estimation results (potential market factor, $t = 5.0$)

Variable type and name		Demand equation Estimate	Demand equation T-Ratio	Pricing equation Estimate	Pricing equation T-Ratio
Constant		-7.699	-22.88	-2.704	-47.15
Country	France	-0.668	-5.50	-0.188	-4.91
	Germany	-1.644	-10.24	-0.133	-3.50
	Italy	-1.816	-12.10	-0.428	-10.33
	Japan	1.365	10.22	0.055	1.48
	United Kingdom	0.205	1.81	0.170	4.74
	United States	-0.588	-4.92	-0.085	-2.32
Intel	386 +below	-0.714	-6.88	-0.172	-5.38
Processor	5^{th} Gen. <= 100MHz	0.804	23.02	0.235	28.75
	5^{th} Gen. 101-149 MHz	1.612	29.49	0.448	51.48
	5^{th} Gen. 150-179 MHz	2.152	29.71	0.618	61.68
	5^{th} Gen. >=180 MHz	2.642	30.26	0.760	68.42
	6^{th} Gen. <= 200 MHz	3.169	29.59	0.902	65.99
	6^{th} Gen. 201-299 MHz	3.345	31.09	0.947	77.90
	6^{th} Gen. 300-399 MHz	3.616	31.24	1.032	79.36
	6^{th} Gen. 400-499 MHz	3.898	31.11	1.146	81.83
	6^{th} Gen. 500-599 MHz	4.307	30.01	1.277	71.41
	6^{th} Gen. 600-699 MHz	4.700	26.65	1.389	44.50
	6^{th} Gen. 700-799 MHz	5.082	16.38	1.624	19.67
Motorola	<= 68030	-0.965	-5.68	-0.477	-8.67
Processor	68040	-0.172	-1.12	-0.194	-4.45
	PowerPC	2.074	15.89	0.554	15.12
Quarter	Q1	0.509	23.34	0.133	25.00
	Q2	0.156	8.70	0.073	14.08
	Q4	0.394	22.72	-0.069	-13.48
Year	1995	3.914	31.49	1.168	97.57
	1996	3.204	31.14	0.947	93.35
	1997	1.937	28.84	0.605	70.94
	1998	0.970	26.32	0.295	45.94
Type	Desktop	3.119	52.30	-0.414	-42.45
	Laptop	2.185	63.90	0.088	9.36
OS	DOS/WIN	1.129	3.47	-0.070	-1.23
Vendor	Nec/Packard Bell	0.034	0.47	0.013	0.56
	Compaq	0.025	0.39	-0.030	-1.47
	Gateway	-0.256	-3.09	-0.010	-0.39
	IBM	-0.034	-0.49	-0.016	-0.74
	Hewlett-Packard	0.507	4.06	0.133	3.37
	Toshiba	0.629	6.98	0.092	3.27
	Dell	0.754	9.15	0.204	8.00
	Acer	-0.141	-5.45	-0.024	-2.88
	Fujitsu	0.286	8.44	0.050	4.88
	AST	-0.135	-3.33	-0.019	-1.50
	Siemens	0.261	6.75	0.090	7.57
	Olivetti	0.067	1.52	0.060	4.25
	Vobis	-0.139	-2.92	-0.047	-3.11
	Elonex	0.282	3.60	0.011	0.45
	Epson	-0.198	-2.95	0.040	1.85
	ESCOM	-0.513	-4.02	-0.234	-5.82
	Sony	0.314	4.94	0.048	2.46
	Others	0.589	6.85	0.088	3.39

Table 8b (Continued)

Interaction	Compaq – France	0.299	3.58	0.172	6.45
	Compaq – Germany	-0.401	-4.44	0.013	0.45
	Compaq – Italy	-0.228	-2.78	0.010	0.36
	Compaq – Japan	-0.260	-3.11	0.008	0.32
	Compaq – U.K	0.225	2.62	0.150	5.54
	Compaq – U.S	0.201	2.48	0.026	1.02
	IBM – France	0.332	3.74	0.115	4.07
	IBM – Germany	0.611	6.14	0.239	7.78
	IBM – Italy	0.014	0.15	0.071	2.39
	IBM – Japan	0.584	6.71	0.095	3.42
	IBM – U.K	0.501	4.70	0.104	3.07
	IBM – U.S	0.380	4.17	0.086	2.97
	HP – France	-0.459	-3.32	-0.079	-1.79
	HP – Germany	-0.254	-1.82	0.039	0.87
	HP – Italy	-0.435	-3.07	-0.086	-1.92
	HP – Japan	-0.050	-0.25	0.103	1.67
	HP – U.K	-0.628	-4.42	-0.155	-3.40
	HP – U.S	-0.234	-1.75	-0.055	-1.29
	Nec/P.Bell – France	0.173	1.83	0.034	1.11
	Nec/P.Bell – Germany	0.314	3.24	0.115	3.83
	Nec/P.Bell – Italy	0.406	4.41	0.138	4.74
	Nec/P.Bell – Japan	0.045	0.49	0.008	0.27
	Nec/P.Bell – U.K	0.014	0.15	-0.062	-2.08
	Nec/P.Bell – U.S	0.071	0.80	-0.040	-1.40
	Gateway – France	0.395	3.94	0.069	2.14
	Gateway – Germany	0.630	6.24	0.158	4.99
	Gateway – Japan	0.279	2.64	0.100	3.01
	Gateway – U.K	0.183	1.84	-0.003	-0.08
	Gateway – U.S	0.724	7.23	0.102	3.29
	Toshiba – France	-0.440	-4.01	0.040	1.13
	Toshiba – Germany	0.088	0.81	0.192	5.68
	Toshiba – Italy	-0.951	-8.40	-0.114	-3.20
	Toshiba – Japan	-0.083	-0.77	-0.158	-4.63
	Toshiba – U.K	-1.040	-9.50	0.051	1.45
	Toshiba – U.S	-0.676	-6.32	-0.057	-1.66
	Dell – France	-0.775	-7.47	-0.133	-4.04
	Dell – Germany	-0.353	-3.14	-0.004	-0.11
	Dell – Italy	-0.789	-7.47	-0.144	-4.39
	Dell – Japan	-0.677	-6.02	-0.182	-5.12
	Dell – U.K	-0.434	-4.43	-0.099	-3.15
	Dell – U.S	-0.471	-4.49	-0.156	-4.70
	Others – France	-1.260	-10.62	-0.420	-11.61
	Others – Germany	-0.553	-4.91	-0.095	-2.65
	Others – Italy	-0.274	-2.46	-0.043	-1.20
	Others – Japan	-0.671	-5.61	-0.148	-3.99
	Others – U.K	-0.574	-5.18	-0.083	-2.36
	Others – U.S	-0.299	-2.86	-0.053	-1.57
	DOS/WIN – France	0.255	1.98	0.128	3.10
	DOS/WIN – Germany	1.507	8.85	0.120	2.92
	DOS/WIN – Italy	1.289	8.36	0.253	5.72
	DOS/WIN – Japan	-0.011	-0.08	0.155	3.83
	DOS/WIN – U.K	-0.085	-0.71	-0.066	-1.69
	DOS/WIN – U.S	0.813	6.27	0.215	5.46

Table 9: Estimated elasticities and markups for some brands

Vendor	Brand	Vendor Brand / Form Processor	Compaq Presario / Desktop	Dell Dimension / Desktop	IBM Thinkpad1 / Small laptop	HP Omnibook / Laptop	Apple Power Mac / Desktop	Price $	Markup Percent
Compaq	Presario	P6 – 400	-32.67000	1.21148	0.00003	0.00002	0.00509	1094	3.37
Dell	Dimension	P6 – 400	3.83768	-39.90002	0.00003	0.00002	0.00509	1232	2.67
IBM	Thinkpad1	P6 – 400	0.03952	0.01248	-60.06663	0.00002	0.00193	1823	1.30
HP	Omnibook	P6 – 200	0.03952	0.01248	0.00003	-79.90241	0.00193	2395	1.95
Apple	Power Mac	Power PC	0.10444	0.03297	0.00003	0.00002	-45.96718	1495	28.81

Note: Potential market factor $t = 5.0$, period 1999 Q3, US market.

Table 10: Empirical distribution of elasticities and markups at brand level

	Canada	France	Germany	Italy	Japan	UK	US
Own price	58.212	51.685	56.664	47.357	65.121	55.717	57.806
	29.925	*19.759*	*19.443*	*16.693*	*22.051*	*24.744*	*22.656*
Cross price							
Same form &	3.741	1.061	1.094	1.207	1.817	1.244	1.374
Same operating system	*11.337*	*5.125*	*6.456*	*5.516*	*6.953*	*6.535*	*6.163*
Same form &	0.050	0.012	0.013	0.014	0.024	0.014	0.017
Different operating systems	*0.163*	*0.035*	*0.037*	*0.041*	*0.053*	*0.043*	*0.057*
Different forms	0.007	0.002	0.002	0.002	0.004	0.002	0.002
	0.018	*0.005*	*0.005*	*0.012*	*0.010*	*0.006*	*0.007*
Markup	3.9	2.8	2.4	3.2	2.3	2.8	2.7
	6.2	*3.2*	*2.9*	*3.7*	*3.2*	*3.1*	*3.9*

Note: In each cell, the first number is the empirical mean of the item for year 1999 and the italicized second number is the empirical standard deviation. Here the potential market factor is $t = 5.0$.

Table 11: Estimated elasticities at firm level

	Canada	France	Germany	Italy	Japan	U.K	U.S
Apple	3.52	4.09	3.25	3.59	4.73	5.16	2.99
Compaq	32.75	35.29	39.85	31.70	39.26	43.27	36.96
Dell	45.77	37.96	45.05	35.52	48.38	39.84	40.94
Gateway	Nc	33.59	40.23	Nc	45.56	36.08	36.68
Hewlett-Packard	33.05	33.81	42.32	32.64	Nc	41.20	30.36
IBM	30.61	33.88	43.43	35.42	46.26	40.44	37.60
Nec/Packard Bell	35.71	28.22	35.96	28.50	47.55	39.28	34.13
Toshiba	31.29	37.52	38.15	21.75	45.11	39.88	46.21

Notes: *i)* Potential market factor $t = 5.0$, period 1999 Q3.
ii) When a vendor is not present in a market, the elasticity cannot be computed.

Table 12: Aggregate elasticity at observed prices

Platform	All PCs				DOS/WIN PCs			
Period	1995 Q3	1999 Q3	1999 Q3	1999	1995 Q3	1999 Q3	1999 Q3	1999
Value of t	5.0	5.0	8.0	5.0	5.0	5.0	8.0	5.0
Canada	1.97	1.46	1.67	1.73	2.82	1.74	1.92	1.99
France	1.75	1.38	1.55	1.73	2.19	1.55	1.69	1.76
Germany	1.73	1.64	1.83	1.77	1.99	1.85	2.02	1.86
Italy	1.68	1.44	1.59	1.78	1.97	1.63	1.76	1.74
Japan	1.99	1.74	2.02	1.85	3.15	2.20	2.42	2.30
UK	2.13	1.78	1.98	1.81	2.61	1.88	2.07	2.07
US	1.97	1.41	1.60	1.66	2.99	1.77	1.93	2.01

Note: The aggregate elasticity is the percent change in total shipment of all products belonging to a category when each price in that category is increased by one percent.

Table 13: Simulated prices of DOS/WIN

Conduct	Monopoly				Nash			
Period	1995 Q3	1999 Q3		1999	1995 Q3	1999 Q3		1999
Value of t	5.0	5.0	8.0	5.0	5.0	5.0	8.0	5.0
Canada	549	609	591	595	552	601	583	590
France	561	588	573	575	561	585	570	576
Germany	597	617	600	610	587	605	589	603
Italy	nc	581	568	596	Nc	578	564	594
Japan	565	632	613	622	559	622	603	613
UK	562	626	607	601	561	613	596	597
US	566	598	583	603	564	592	576	596

Note: Potential market factor $t = 5.0$.

Table 14: Implicit structure of DOS/WIN producer's objective function

	Weight associated with present income	Weight associated with market share
Canada	9.5	90.5
France	6.2	93.8
Germany	5.2	94.8
Italy	6.2	93.8
Japan	7.5	92.5
UK	5.4	94.6
US	6.6	93.4

Note: Potential market factor $t = 5.0$, all quarters of 1999.

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