Operating System Prices in the Home PC Market[❖]

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Because the demand for OS is a derived demand revealed through the demand for PCs and because its elasticity is relatively small, the profit-maximizing price of DOS/WIN that would result from a static equilibrium is much higher than the observed price. We investigate this assertion empirically by fitting a differentiated-products model of the home PC market to a panel data of all PC brands sold in the G7 countries over the period 1995-1999. The results confirm that the low value of the aggregate elasticity of demand for PCs is the result of differentiation and substitution among PCs.

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I. INTRODUCTION

In most cases, a new computer acquired by a consumer immediately works because of the operating system that is already installed on it. 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.[1] Recognizing that the demand for operating systems is derived from that for the PCs on which they are installed, this paper explores the economic rationale of present OS prices empirically.

As each PC sold comes with an operating system, 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, assuming that PCs are homogenous products.[2] 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. The 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 supplied by softwares often installed together with the OS.

Based on this argument, Reddy, Evans and Nichols [1999] evaluate the profit-maximizing price of OS to be at least equal to $900, much above the observed price of Windows of $60.[3] Note that Fisher [1999] does not reject the preceding argument. He disagrees with an estimate of the aggregate elasticity of demand for PCs close to one. Using a much higher value for this elasticity, he provides an estimate of $90 for the profit-maximizing price of Windows, then relatively close to the observed price.[4] Clearly, the choice of parameter values that play a role in the preceding argument, and in particular the estimate of the aggregate elasticity of demand for PCs, is a crucial issue that involves at least two aspects.

First, the choice of assumptions on which the preceding argument is based can be discussed. In particular, the assumption of product homogeneity does not seem reasonable with respect to the apparent differentiation of computers.[5] Given that each PC brand is likely to face a different demand elasticity, it is critical for our purpose to account for heterogeneity. Applying the much simpler hypothesis of product homogeneity would be a potential source of bias for the estimation of the aggregate elasticity because we would not take into account the imperfect substitutability among products. The question is how PC heterogeneity and substitutability could affect the estimate of the aggregate elasticity for OS and hence the discrepancy between the observed and profit-maximizing prices of OS.

Second, behind the previous argument 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 have been known since Marshall.[6] A low elasticity of derived demand for a specific input is expected when the following conditions are fulfilled: 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. In what follows, we put aside the fourth condition which is hard to test, we consider that the third one is satisfied for any PC and we focus our attention on the first two conditions.

To empirically test these conditions, to infer the aggregate elasticity of demand for operating systems and to assess the OS prices, we estimate the demand for PCs by performing an econometric test on real data that allows us to take into account the differentiation in the PC industry.

The literature on differentiated products, and in particular the econometrics of differentiated product markets, invites us to achieve our objective through a structural model of demand and supply. 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 market 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. These results do not fill the need of deriving an estimate of the aggregate elasticity of demand for PCs (and hence for OSs) as they do not a priori imply a low aggregate elasticity, which is implicitly required in the argument presented above.

The structural model we build to analyze the home PC, which follows the line of the approach taken by Verboven [1996] for the automobile industry, entails several assumptions. For instance it assumes a nested logit model for the demand side. How these assumptions of specification affect our findings, and in particular our estimates of the aggregate elasticity and the OS prices, is an important issue. Although *a priori* the nested logit model has a relatively limited flexibility to approximate preferences, we advocate that it provides results that are not counterintuitive. Moreover, we stress an important feature of the logit-type models. They usually entail a normalization, which here bears on the size of the market or on the market share of the good that is an alternative to buying any new PC. We propose to somewhat relax the constraints of the nested logit model by allowing the market size to change and to evaluate the effect of this change on the estimates of the aggregate elasticity. Finally, the robustness of these estimates also determines the economic relevance of this study. For this reason, we provide confidence intervals for the aggregate price elasticities as well as confidence intervals for the profit-maximizing OS prices.

To estimate our structural model and to obtain an aggregate elasticity, data covering the whole market are required. They are extracted form a database assembled by International Data Corporation (IDC). 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 segment for a technical reason. By concentrating on the home segment, we can largely ignore the question of how to handle purchases of multiple units. This is not true for large businesses, for example, which typically purchase and own multiple PCs. Restricting attention to the home segment is not too limiting however. Indeed the home segment plays a crucial role in the evolution of the information technology industry because of its scope and size.[7] Finally, another advantage of looking at the home PC market for our purpose is that it is stable over the period 1995-1999 in the sense that, in this market over this period, the choice is limited to the Wintel platform, i.e., PCs equipped with an Intel processor and a version of Windows, and Apple-MacOS platform. This situation avoids us to model the dynamics created by the network effects which play a crucial role in the PC industry. Instead we cast the working of the home market in a static set up and we empirically identify the effect of the installed base of PCs on the valuation of PCs.[8]

The data are extensively discussed in section II. Based on the features of our database, we devote section III 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 IV, the model is fitted to the panel data set. In section V 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 IDC database provides breakdowns of PC shipments (the quantity produced and shipped to distributors) and prices by vendor (i.e., manufacturer), brand, form factor (i.e., whether it is a desktop or a notebook for instance), processor speed, region and customer segment.[9] Quarterly data are available since the first quarter of 1995. Our data set covers 20 quarters, until the fourth quarter of 1999. 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 are reasonable for this segment. 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.[10] 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 represents a 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. All together US households account for roughly half of the total US installed base of PCs.

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. 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 computers with PowerPC processors, designed primarily to run the Macintosh OS, that otherwise meet the basic criteria, and any product that meets the definition of PC server, even though PC servers are not single-user devices (…)."[11] 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 whose shipments are measured in the IDC database. Indeed by restricting attention the home market, we are left with two platforms only, each characterized by a single family of processors and a single family of operating systems. The first platform, called the DOS/WIN platform, gathers all variants and versions of DOS and Windows installed on machines powered by Intel-compatible.[12] The second platform, called the MacOS platform, is mainly produced by one vendor, Apple, and combines a version of the MacOS with a Motorola or PowerPC processor.[13] In other terms, on the home segment, there is a one-to-one relationship between the processor type and the (unobserved) OS.

The DOS/WIN platform reaches a 95% market share on average as shown in Table I. The market share of the DOS/WIN platform has a relatively larger variance and falls in a range between 1.5% for Germany and 12% for Japan.

[Place Table I about here]

Features of the home segment[14]

All together our database on the home PC market contains 23701 observations. 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, the picture is different. The industry comprises "local" firms sometimes quite large in a single country but often quite small worldwide. Often multinational firms have relatively small market shares outside their home countries. From inspecting the data, several facts can be noticed. Only seven vendors exceed the one-percent market share threshold in each of the five years over the period 1995-1999. Only four firms present in the seven countries meet the same criteria. Hence the industry is not concentrated.

The ten largest vendors (the first ten vendors ranked by decreasing market shares, i.e., the top 10) in at least two countries over the period 1995-1999 are provided in Table II. Note that this list differs from one country to another. In each country there are "national champions" that are not present in the other countries. Note the large market share reached the category "Other top 10" that includes all vendors that are in the top 10 in only one country.[15] In addition, Table III displays the G7 shipments and market shares for the ten largest firms in each year. Note that the ranking evolves significantly over time and so the volatility of market shares across PC brands. Given these facts, we may draw two conjectures. First, competition in the home PC segment that is growing fiercer over the period; second this market segment exhibits significant idiosyncrasies among countries.

[Place Table II about here]

[Place Table III about here]

[Place Table IV about here]

Differentiation is not an empty word in this industry. First, 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. According to Table IV, the number of brands, which is correlated with the population size, is slightly increasing over time for most countries. Second, PCs differ in their form, the so-called factor form. For the home segment, three form factors are usually identified: desktop, laptop or notebook, and ultra portable. Table V shows that the share of notebooks and ultra portables increases over time and it is much larger in Japan than in any other country.

The speed of processors could be an additional candidate of market differentiation. Over the period 1995-1999 different generations of Intel-compatible processors appeared and disappeared. Basically each year a new processor with an increased speed becomes available. Now, as the length of life of each Intel processor generation is around three years and since the old generation disappears from the market as soon as a new one arrives, most PC brands shipped to different destinations in a given year can be equipped with five different leading types of Intel processors.[16] As far as the MacOS platform is concerned, 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.[17] Clearly this dimension of differentiation in terms of processor type would be meaningful in an intertemporal approach.

Finally, the database also provides prices of the different brands. 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." According to Table VI, the temporal pattern of annual average prices for each country exhibits a decreasing trend. Note that these average prices are not controlled for the differences in the technical characteristics of PCs shipped in the different countries. The overall mean is equal to 2205 in 1995 and it is only 1783 in 1999. In addition the standard deviations of the price distribution in each year and in each country show a large price variability. Again these facts support the view that competition is getting fiercer over time.

[Place Table V about here]

[Place Table VI about here]

III. THEORETICAL MODEL

The key features of the data are the price volatility and the degree of product differentiation and variety. Fully recognizing this fact, the model below allows us to characterize supply and demand side effects in order to explain price differences and the behavior of vendors. This model has two main components: a demand system, which is based on the nested logit model, and a supply system derived from a Nash equilibrium.

Demand system

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 to buy no computer at all.

Given our data, three choices seem relevant: form factor, client operating system, and brand.[18] We assume that they are arranged in the following order. 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 *D*, laptop *L* and ultra portable *U*. Let *g* be the choice made by the consumer in the choice set $G = \{D, L, U, O\}$. 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).

This sequence of choices corresponds to a natural order in the sense that the hardware form is selected before the software. An alternative sequence consists of inverting the first two decisions by choosing first the operating system, then the PC form, and finally the PC brand. This order would be more realistic when the customer is aware of the working of a PC product and its environment. Which sequence of choice is relevant is left as an empirical issue.

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

(1) $$U^n_{khg} = \overline{V}_{khg} - \alpha p_{khg} + \xi + \xi_{khg} + \varepsilon^n_{khg} ,$$

where $\overline{V}_{khg}$ is a deterministic part that depends on the specific brand, operating system and form factor chosen by the consumer, ξ is a market specific component, ξ_{khg} is a random term reflecting the effect of unobserved characteristics of brands on the mean utility, p_{khg} is the price of the selected product, α is the *marginal utility of income* and is a parameter of interest to be estimated and ε^n_{khg} defines the unobserved variables that explain the departure of consumer *n*'s behavior from the common utility level. The random term ε^n_{khg} is specified as a weighted sum of unobserved variables as follows

(2) $$\varepsilon^n_{khg} = \nu^n_g + (1 - \sigma_H)\nu^n_{hg} + (1 - \sigma_K)\nu^n_{khg}, \ \forall n = 1, ..., N$$

where σ_H and σ_K are parameters to be estimated. The random components are assumed to be distributed in such a way that they give rise to the nested logit model. (See Ben-Akiva and Lerman [1985] or McFadden [1981] for details.) In the sequel, we drop the indices *h* and *g* when there is no confusion.

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 nested logit model. First the higher σ_K, the higher the correlation between products of the same sub-group, i.e., the same client operating system, and the higher σ_H, the higher the correlation between products of the same group, i.e., the same form factor. Second, the parameters must satisfy $1 \geq \sigma_K \geq \sigma_H \geq 0$ for the model to be consistent with stochastic utility maximization.

Finally, aggregating these probabilities over all consumers generates market shares. Using simple algebra and some normalizations, s_k, the share of product *k* in a market, can be written in logarithmic form as

(3) $$\ln s_k = \overline{V}_k - \alpha p_k + \sigma_K \ln s\left(k \middle| h, g\right) + \sigma_H \ln s\left(h \middle| g\right) + \ln s_0 + \xi + \xi_k ,$$

where now $s\left(k \middle| h, g\right)$ designates the share within the nest defined by form factor *g* and operating system *h*, $s\left(h \middle| g\right)$ 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.[19]

The different shares are measured as

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

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 for deriving the expressions of 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*.[20]

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.,

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

where c_k, the marginal cost of producing brand *k*, is constant.[21,22] Assume Nash-Bertrand competition for the home PC industry in each separate market and consider demand functions as specified in the preceding section. The markup π_k, for each product *k* belonging to the nest (h, g), is given by[23]

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

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

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

The existence of a solution to the set of Equation (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 (6)-(7) show that the markups take values on a restricted set. Indeed they are only determined by only three parameters of interest $\alpha, \sigma_K, \sigma_H$, 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 in the continuity of the function defining the markups.

IV. SPECIFICATION ISSUES

The demand Equation (3) and the pricing Equation (6) form a simultaneous equation system in the sense that prices and quantities are jointly determined. This system is estimated by applying the nonlinear three-stage least-squares estimator, once some additional elements of specification are settled. They concern the final parameterization of the demand and pricing equations, the marginal utility of income, the choice of market size, the estimation method and the selection of instruments.

Final parameterization of the demand and pricing equations

The deterministic part of the indirect utility for each product is specified as a linear combination of available exogenous variables, among which a specific effect of the firm that produce this brand and dummy variables for the type of OS, PC form factor, and processor that characterizes this particular brand. The market-specific variable ξ in Equation (3) is specified as a set of dummy variables referring to countries and time periods, also allowing for cross effects between countries and firms and between countries and OS. Let *x* be the set of all these variables. The precise elements of this vector are provided below together with the estimation results.

Using the market index m and the notations introduced so far, the demand equation is now stated as

$$\ln \frac{q_{km}}{N_m - \sum_{k \in K_{hg}, \forall h,g} q_{km}} = x_{km}\beta - \alpha_m p_{km} + \sigma_K \ln \frac{q_{km}}{Q_{hgm}} + \sigma_H \ln \frac{Q_{hgm}}{Q_{gm}} + \xi_{km} , \tag{8}$$

where β is a vector of parameters to be estimated. Note that the parameter α is supposed to be country specific.

Concerning the pricing equation, we specify the marginal cost as

$$c_{km} = \exp\left(x_{km}\gamma + \zeta_{km} \right) , \tag{9}$$

where γ is a vector of parameters to be estimated and ζ is a random term that stands for the unobserved component of the marginal cost. Based on Equation (9), the pricing equation becomes

$$\ln\left(p_{km} - \pi_{km} \right) = x_{km}\gamma + \zeta_{km} \tag{10}$$

At this point, note that the pricing equation can be viewed as a hedonic price equation that satisfies behavioral and structural constraints through the markup. In other words, it shows that just considering a standard hedonic price equation for analyzing the pricing behavior in this differentiated-products market would certainly cause a misspecification.

Specification of the marginal utility of income

The marginal utility of income α is assumed to vary across countries. More specifically, this parameter is made function of the Gross National Product per capita (in current USD), in each country in each year, according to:

$$\alpha_m = \alpha_0 + \alpha_1 GNP_m , \tag{11}$$

where α_0 and α_1 are parameters to be estimated. In addition to providing a more flexible model, this specification introduces a wealth effect. If GNP per capita is a proxy for wealth, one should expect α_1 to be negative. Richer countries might be expected to be less sensitive to PC prices. Note that, by specifying the parameter α as in Equation (11), we introduce a trend in the model through GNP.

Choice of the market size

While not stressed in the literature, the choice of the market size plays an important role in the measurement of elasticities, and in particular the measurement of the aggregate elasticity for PCs. To see that, note that the aggregate elasticity depends in part on the amount of utility received from all the “inside” goods relatively to the utility level provided by the sole outside good. From Equation (8), we can define the gross utility level, i.e., $\delta_{km} = x_{km}\beta + \xi_{km}$, as

$$\delta_{km} = \ln \frac{q_{km}}{N_m - \sum_{k'} q_{k'm}} + \alpha_m p_{km} - \sigma_K \ln \frac{q_{km}}{Q_{hgm}} - \sigma_H \ln \frac{Q_{hgm}}{Q_{gm}} .$$

If the structural parameters α and σs do not vary much, the gross utility level provided by each PC decreases as the market size gets larger. The outside alternative becomes more attractive and the aggregate elasticity increases. So changing the market size is changing the value of the outside alternative and the level of the aggregate elasticity.[24] It is then a crucial task to determine the potential market size N_m, i.e., the potential number of consumers in each country, and to test how it affects the estimates.

A standard measure used by several studies in the literature is the number of households. One may question the relevance of this measure. Since a PC is an object of individual usage (particularly when we consider laptops), one might admit that the size of the population is more appropriate for the home PC segment than for the automobile market for instance.

An admissible range for the market size is easily defined. Clearly, on one side, the population is an excellent candidate for an upper bound of the potential market size. Indeed, some individuals are not able to buy PCs, like babies for instance; some others have bought a PC equipment recently and are not considering renewing it. On the other side, a lower bound for this market size is obviously the total amount of PC shipments to the home segment, which would imply that no consumers choose the outside good.

Since the right potential market size (in the range defined by the population size and the total volume of shipments) is not known, we propose to select several values in this range in order to check for the robustness of our results. We proceed as follows. Given the two identified bounds of the range of values; the market size could be either proportional to the population size or to the total amount of PC shipments to the home segment. We adopt the second option and we set the total number of potential consumers as the average annual shipments of PCs in a country multiplied by a number τ that we call the *market size factor*. The motive for our choice is simple. The population size does not change much year by year and so, is not able to account for the rapid diffusion and attractiveness of PCs in the population. Note that a log-log relation between the number of households and the total quantity of PCs shipped in a year (with or without constant) provides a R^2 equal to 99%. As the total quantity of PCs shipped in a year is able to reflect the dynamics in this industry, it is an excellent candidate to calibrate the market size here.

It remains to select values for the market size factor. Admissible values are all strictly greater than one. The value one corresponding to the lower bound cannot be used because of the logarithmic form of the demand equation given by Equation (8). In effect a value of τ slightly greater than 100 provides a market size that is roughly equal to the population size on average.

In practice, the measure of market size is obtained as follows. First, for each country and each year, we compute average quarterly total shipments. Second, we inflate this number by the market size factor τ taking values in the range [2,100]. This method permits us to obtain a potential market size that is country-specific and annually modified. Allowing the market size to change over time provides us with more flexibility.

Estimation method and choice of instruments

Summing up, in the system formed by Equations (8) and (10), the parameters to be estimated are the β s, the γ s, the α s, σ_K and σ_H. Note that a subset of parameters including the β s and α_0, α_1, σ_K and σ_H, could be estimated directly from the demand equation without the need of the pricing equation. However, estimating the two equations together improves the quality of estimates.

This system of Equations (8) and (10) contains several endogenous variables: price, shipment quantity, and shares of different nests in the decision tree. Following the usual practice, the characteristics of PCs are assumed to be exogenous, an assumption that allows us to identify the model. In a long run perspective, it would be a too strong assumption, as the choice of computer characteristics by firms might result from a strategic behavior in a dynamic setting. Here, considering a short run horizon and recognizing that the sole characteristic we observe is the processor speed, it is fairly reasonable to assume that the level of technical progress on processors is a state variable for PC vendors.

A further aspect of this econometric model is that the error terms ξ and ζ may be correlated. In these conditions the nonlinear three-stage least-squares estimator is an adequate choice given the structure of the econometric model. This method requires choosing a set of instrumental variables.

Given the variables available in our data set, there are not too many alternatives. The set of instruments chosen here 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 of brands per operating system, the number of brands per type and speed of processor, 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 trying different combinations of variables. This choice is in the line of a tradition initiated by Berry, Levinshon and Pakes (1995).

V. EMPIRICAL RESULTS

Parameter estimates

Table VII presents the sets of estimated parameters of interest, corresponding to the different values for the market size σ_K and σ_H discussed above. Clearly these estimated values are stable from one experiment to the other. However, note that, as market size increases, α_0 decreases, α_1 increases, and the combined effect is that the marginal utility for money α_m slightly decreases. The intra-group correlations σ_K and σ_H (i.e., PCs sharing the same OS and the same form factor and PCs sharing the same form factor) also decrease.

Several other remarks about Table VII are in order. First, all parameter estimates are significantly different from zero in all experiments. Note that, as σ_K and σ_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. In other words, differentiation matters along these two dimensions, i.e., OS and PC form. Second as expected, α_0 is positive and α_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 α_m defined by Equation (11) is always positive. Fourth, the parameter σ_K is greater than σ_H, which is required for the model to be consistent with utility maximization.[25]

[Place Table VII about here]

Table VIII presents the other parameter estimates for $\tau = 5.0$.[26] 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, everything being equal, the higher value in term of utility associated with the desktop dummy compared to the laptop or small portable dummies picks up an un-modeled distribution of tastes in the population over the ‘portability versus price’ combinations.[27] Third, as expected, a desktop has a lower marginal cost. Fourth, 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 to the DOS/WIN network.

As far as the time variable is concerned, note that the quarterly effect seems realistic. Demand is 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 of year on utility levels could be interpreted as an effect of satiation of demand. This last statement merits further comments.

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. A coherent series for the equipment rate can be downloaded from the World Bank web site. This equipment rate in PCs, which measures the importance of the installed base, appears to be strongly trended, with the trend being country specific. Then the decreasing time effect of year on utility levels could be due to 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 in turn affected 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.

[Place Table VIII about here]

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 (in particular country-time fixed effects) either does not significantly improve the goodness-of-fit of the model or leads to convergence problems.

Last, we provide the first stage R-squared associated with each parameter as a ‘measure of quality’ for the instruments used at the estimation stage. These values determine the acceptability of the selected instruments in measuring the fraction of the variation of the derivative of the objective function associated with the parameter that remains after projection through the instruments. Ideally, the R-squared should be close to 1 for exogenous derivatives. In our case, the R-squared values are exactly equal 1 for each parameter associated with an exogenous variable. For the parameters of interest α_0, α_1, σ_K and σ_H, the R-squared values are 0.54, 0.68, 0.42 and 0.83, respectively. These values are large enough to reflect a good choice of instruments for the endogenous variables.

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 IX, and some statistics on the overall distribution of these estimated elasticities and markups at the brand level are provided in Table X. Table XI 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.

[Place Table IX about here]

[Place Table X about here]

[Place Table XI about here]

Before discussing these elasticities and markups, it is useful to return to Table VII and to assess the values taken by the parameters of interest, in particular σ_K and σ_H. Indeed, these parameters play a crucial role in the formulas of the different types of elasticity. (See the Journal's editorial Web site which provides the formulas of elasticities in Appendix C of our supplemental document.) First, because σ_K is significant and close to (although statistically different from) one, PC brands are close 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 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 X or the cross elasticity between the Compaq Presario and the Dell Dimension in Table IX.) Second, because σ_H is significantly different from zero and is not close to σ_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 Table X.

Two main remarks can be made on the estimates of elasticities and markups. First, the own-price elasticities at the brand level for all types of PCs (whether they are run under DOS/WIN or MacOS) are high. (See Table IX.) One could blame the nested-logit model for these results, because, as we explain above, the flexibility of this model to represent preferences is limited. However these results are not counterintuitive. Indeed, as a PC is a durable good for a household, i.e., a commodity that is bought once for a "long period", 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. Moreover, the quartile ranges for the own-price elasticities reported on Table X show that the median is systematically lower than the mean and the distributions appear to be more concentrated on low values. So our model is able to account for large variances and asymmetric patterns. Second, we observe that the price elasticities at the firm level are quite high for all PCs based on the DOS/WIN platform and are much smaller (higher) for PCs based on the MacOS platform. (See Table XI.) The corollary of this result is that any DOS/WIN PC has a rather small markup while any MacOS PC has a very high markup. (See Table IX again.) This result indicates that the home segment of the PC manufacturing industry is highly competitive. Now, the fact that we observe simultaneously high own price elasticities at the brand level and high markups for MacOS products 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 and probably amplifies the phenomena.[28]

Aggregate elasticity of PCs

Table XII provides our estimates of the elasticity of aggregate demand of household PCs, for all the G7 countries for the third quarter of 1999 and for different values of market size. The aggregate 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. For each country *m* at each period *t,* the aggregate elasticity e_{tm} is defined according to

(12) $$e_{tm} = \left. \frac{\partial \log\left[\sum_{j\in A_{tm}} s_j\left(\lambda p_{tm}\right) \right]}{\partial \lambda} \overline{p}_{tm} \right|_{\lambda=1} = -\alpha_{tm}\overline{p}_{tm}s_0 \,,$$

where A_{tm} is the set of all products sold at period *t* in country *m*, s_j is the share of computer *j* (See the Journal's editorial Web site for a presentation of the demand system in Appendix B of our supplemental document), p_{tm} is the vector of observed prices and $\overline{p}$ is the share weighted average price for the outside good. (See Werden [1997].) This formula shows that the aggregate elasticity would be affected by the choice of market size through the market share of the outside good. Confidence intervals for the estimates of this aggregate elasticity can then be computed by applying the delta method to the function f_{tm} defined by Equation (12).

[Place Table XII about here]

First, note that our estimates of the aggregate demand elasticity for the third quarter 1999 are highly sensitive to the choice of market size. The elasticity corresponding to the upper bound of experiments (when market size is equal to the population size) is 1.5 to 2 times the value corresponding to the lower bound ($\tau = 2$). Second, these elasticities are very precisely estimated as the mean standard error over countries and market sizes, equal to 0.149, is small compared to the mean values. For instance, the mean elasticity over countries at the market factor $\tau = 5$ is 2.05, with the lowest value being taken by Germany, namely 1.53, and the highest value by Japan, i.e., 3.02. (These values are mid points of the corresponding confidence intervals.) Given that the demand of OS is a derived demand, these numbers are fairly reasonable and realistic.

We may also compute 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. The elasticities for DOS/WIN PCs alone are in general slightly higher, with 1.99 for the U.S and 3.13 for Japan. These results – a complete set is available from the authors - are to be compared to their counterparts for the whole market, i.e., 1.93 for the U.S and 3.02 for Japan.

VI. COUNTERFACTUALS

The estimated model of the home PC segment allow us 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.

In computing the profit maximizing price of Windows below, we assume that Microsoft proposes a unique linear price. However, it is known that Microsoft offers discounts to the major OEMs (which accounts for not more than 60% of the market all together) and not to all PC producers.[29] We have no information on these contracts and we are just able to construct an average price paid by OEMs for licensing Windows 95 or 98. Empirical evidence on the effects of nonlinear prices on the measure of market power has not received a considerable attention in the literature based on structural econometrics. (See however Ivaldi and Martimort, 1994, Brenkers and Verboven, 2002, Miravete and Röller, 2003, Villas-Boas, 2003.) It is a complex question. One main difficulty is that non linear price schemes are not exogenous and must be determined at the equilibrium together with the parameters that characterize demand and supply. Note however that our approach is compatible with two-part tariffs. In effect, in our model, the fixed part of any two-part tariff cannot be separated out from the marginal cost, which would be required to obtain the profit-maximizing two-part tariffs. As price schedules are not observed, this identification problem cannot be solved.

The Nash monopoly price

Consider the situation where the seller of DOS/WIN maximizes its profit assuming that buyers of DOS/WIN, who are sellers of PCs, choose their best strategy in prices. The equilibrium price in this case is called the *Nash monopoly price* of DOS/WIN.[30] 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. As already discussed, the price p_w is assumed to be constant across computer vendors. 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

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

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 given, 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 basic program of an OEM is given by Equation (5) where the consumer price p_k is decomposed into $\overline{p}_k^w + p_w^*$. The OEM chooses $\overline{p}_k^w$ for each product *k* while taking the optimal strategy p_w^* of Microsoft as given. The first order condition associated with product *k* is given by Equation (6) in which we replace the observed values of Q_g, Q_{hg} and Q_{hg}^f by their theoretical counterparts in terms of logit probabilities. The system formed by Equation (17) and by the transformed Equation (6) must be solved numerically at the estimated values of the parameters. 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 XIII gathers the confidence intervals for the simulated Nash monopoly prices that we obtain for the G7 countries in the third quarter of 1999 and for the different market sizes. These confidence intervals are computed by using the delta method again.[31] First, wholesale prices of PCs increase. Given the small margins we find for DOS/WIN PCs, 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 pass-through is here almost complete, indicating that OEMs do not have a strong countervailing power. Second, all monopoly prices are precisely predicted. For instance the largest value for the standard errors is $22.42 for the U.S when the market size factor is $\tau = 2$. Third, the smallest lower bound of our confidence interval is $497 while the largest upper bound is $698. The range is mainly affected by the choice of market size. Indeed, as expected, the larger the potential market size, the larger the monopoly price even if the OS prices are less sensitive to the choice of market size than the aggregate elasticities. Finally, the Nash monopoly prices take values that are roughly ten times the actual price of DOS/WIN (around $ 50-60), and three times the sum of the actual DOS/WIN price and the average price of the basic Microsoft's DOS/WIN applications (like Word, Excel, Powerpoint) that Microsoft can expect to sell as complements to the operating system and are evaluated to cost around $200 all together.[32]

[Place Table XIII about here]

To assess the robustness of our findings, an anonymous referee suggested that we perform an experiment consisting in dropping all PCs with prices larger than $5,000, which represent 0.83% of the whole sample. Indeed we do not want high price outliers to help identify the marginal utility for income and the correlation parameters which controls the substitution patterns for all computers. We re-estimate the model for $\tau = 5$ and find $\alpha_0 = 16.332$, $\alpha_1 = 0.264$, $\sigma_K = 0.941$ and $\sigma_H = 0.361$. Note that the sign of α_1 is now counterintuitive although the marginal utility of income remains positive as expected. We remark also a slight decrease of α_0 and an large increase of σ_H. With these new estimates, the aggregate elasticity becomes 1.82 and the monopoly price is now $575, in the case of the U.S. in the third quarter of 1999. Recall that these values are 1.93 and $568 respectively when we use the whole sample. For other countries and/or other periods, elasticities and simulated monopoly prices do not vary much either.

Our estimated profit-maximizing prices of Windows are below the estimate of $900, provided 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 but independent demands, the present price of Windows turns out to be the profit-maximizing price when one considers plausible values for the market parameters.[33] 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 mainly show that, with a differentiated-products model estimated on actual data and taking into account substitution among PCs, the profit-maximizing price is still much higher than the present price of DOS/WIN.[34]

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. The plaintiffs' and defendant's sides at the antitrust trial provide 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.[35] (See, on these questions, Schmalensee [1999], Fisher [1999], Fisher and Rubinfeld [2000], and Evans and Schmalensee [2000].) The agreement ends here. For one side, the level of observed OS prices is the outcome of potential or effective competition. For the other side, it is compatible with a firm having a monopoly power. In both cases it means that the DOS/WIN price is chosen from a different program. To support this view, it is worth mentioning that the true objective function of an OS producer should reflect a trade-off between present and future profits. As Fudenberg and Tirole [2000] point 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. From our estimations, we could easily show that the actual price of Windows is indeed consistent with the maximization of a convex combination of present and future profits.

VII. CONCLUSION

By fitting a simple equilibrium model of the home PC market on a large data set, we provide evidence that the static profit-maximizing price of Windows under monopoly might be much higher than the observed price even if one adds to this market price of Windows, the cost of Microsoft's complementary products (like Word, Excel, Access, Powerpoint). 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. However, what the study mainly shows is that this low value of the aggregate elasticity of demand is the result of differentiation and substitution among PCs, which contradicts the Werden's assertion.

Note 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.[36] 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. 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 it can be 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.

Table I: Average market shares by platform type and country

	DOS/WIN	Mac OS
Germany	98.50	1.50
United Kingdom	97.02	2.98
Italy	95.40	4.60
United States	94.68	5.32
Canada	94.54	5.46
France	94.35	5.65
Japan	88.01	11.99

Table II: 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 the market shares of the ten largest vendors (the top 10) in at least two different countries are reported. The category "Other top-10" refers to a group of vendors that are in the top 10 in only one country. Shares are averaged over the sample period 1995 – 1999. Figures are percentages. The category "Others" gathers the vendors that are unknown by IDC.

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

	1995		1996		1997		1998		1999	
	Share	Shipment /1000	Share	Shipment /1000	Share	Shipment /1000	Share	Shipment /1000	Share	Shipment /1000
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) and shipments of the 10 largest vendors (the top 10) are reported for each year.

Table IV: 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 V: Average market shares by PC form per country and year

	Desktop		Notebook		Ultra portable	
	1995	1999	1995	1999	1995	1999
Canada	92.90%	87.06%	6.94%	12.81%	0.16%	0.13%
France	96.68%	95.36%	3.24%	4.43%	0.09%	0.20%
Germany	95.92%	94.73%	4.07%	4.48%	0.01%	0.80%
Italy	94.93%	90.67%	4.97%	8.55%	0.10%	0.78%
Japan	70.11%	52.91%	20.36%	33.83%	9.52%	13.26%
UK	98.17%	95.83%	1.82%	4.02%	0.00%	0.15%
US	93.65%	92.37%	5.85%	7.13%	0.51%	0.51%

Table VI: 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 VII: Estimates of parameters of interest

Parameters	α_0		α_1		σ_K		σ_H	
Market size	Estimate	T-Ratio	Estimate	T-Ratio	Estimate	T-Ratio	Estimate	T-Ratio
$Q(\tau=2)$	20.133	28.7	-0.348	-3.1	0.959	95.5	0.213	2.0
$Q(\tau=3)$	19.058	30.4	-0.255	-2.5	0.947	105.0	0.235	2.3
$Q(\tau=4)$	18.942	30.7	-0.233	-2.3	0.944	106.5	0.231	2.3
$Q(\tau=5)$	18.881	30.8	-0.226	-2.3	0.943	107.0	0.230	2.3
$Q(\tau=6)$	18.844	30.9	-0.223	-2.2	0.943	107.3	0.229	2.3
$Q(\tau=8)$	18.802	30.9	-0.220	-2.2	0.942	107.6	0.229	2.2
$Q(\tau=10)$	18.778	31.0	-0.218	-2.2	0.942	107.8	0.228	2.2
$Q(\tau=100)$	18.702	31.0	-0.215	-2.2	0.940	108.3	0.227	2.2
Population	18.720	31.2	-0.088	-0.9	0.948	107.6	0.217	2.1

Note: $Q(\tau=i)$ is the total number of potential consumers computed as the average annual shipments of PC in a given country times the market size factor τ which takes the value *i*.

Table VIII: Estimation results for market size factor, $\tau = 5.0$

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 IX: Estimated elasticities and markups for some brands

		Vendor Brand	Compaq Presario	Dell Dimension	IBM Thinkpad1	HP Omnibook	Apple Power Mac		
Vendor	Brand	Form Processor	Desktop	Desktop	Small laptop	Laptop	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: Market size factor $\tau = 5.0$, period 1999 Q3, US market.

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

	Canada	France	Germany	Italy	Japan	UK	US
Own price	54.552	49.445	55.751	42.267	67.082	61.034	54.403
	30.746	*16.559*	*17.346*	*10.430*	*21.069*	*24.653*	*19.723*
Own price (median)	49.084	44.415	51.365	40.994	64.152	58.839	52.917
Own price (first quartile)	39.475	36.010	44.824	36.282	54.927	41.557	38.929
Own price (third quartile)	62.852	61.836	63.029	48.214	76.992	78.201	67.784
Cross price							
Same form &	4.109	0.955	0.917	1.197	2.074	1.227	1.381
Same operating system	*12.329*	*4.839*	*4.442*	*4.766*	*8.435*	*4.898*	*4.722*
Same form &	0.053	0.010	0.011	0.013	0.025	0.014	0.017
Different operating systems	*0.176*	*0.024*	*0.030*	*0.034*	*0.058*	*0.039*	*0.036*
Different forms	0.008	0.001	0.001	0.001	0.004	0.001	0.002
	0.019	*0.002*	*0.003*	*0.004*	*0.011*	*0.004*	*0.007*
Markup	4.7	2.7	2.5	3.3	2.1	2.4	2.9
	7.2	*2.7*	*2.9*	*3.5*	*2.8*	*2.6*	*4.2*

Note: Except for the own-price elasticities' quartiles, in each cell the first number is the empirical mean of the item for the third quarter of 1999 and the italicized second number is the empirical standard deviation. The market size factor is $\tau = 5.0$.

Table XI: 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)* Market size factor $\tau = 5.0$, period 1999 Q3.
ii) When a vendor is not present in a market, the elasticity cannot be computed.

Table XII: Confidence intervals at the 95% level for the aggregate elasticity at observed prices

Market size	Canada	France	Germany	Italy	Japan	UK	US
$Q(\tau=2)$	[0.959;1.405]	[1.128;1.404]	[0.890;1.056]	[1.324;1.610]	[1.730;2.318]	[1.210;2.242]	[0.924;1.636]
$Q(\tau=3)$	[1.385;1.795]	[1.371;1.620]	[1.140;1.367]	[1.503;1.907]	[2.328;2.785]	[1.599;2.424]	[1.320;1.930]
$Q(\tau=4)$	[1.593;2.029]	[1.502;1.761]	[1.235;1.614]	[1.583;2.124]	[2.618;3.085]	[1.761;2.600]	[1.497;2.134]
$Q(\tau=5)$	[1.716;2.169]	[1.579;1.845]	[1.284;1.795]	[1.632;2.257]	[2.788;3.262]	[1.854;2.706]	[1.601;2.255]
$Q(\tau=6)$	[1.796;2.261]	[1.630;1.900]	[1.320;1.925]	[1.666;2.343]	[2.899;3.380]	[1.915;2.777]	[1.669;2.336]
$Q(\tau=8)$	[1.896;2.377]	[1.693;1.970]	[1.373;2.090]	[1.711;2.448]	[3.037;3.527]	[1.990;2.866]	[1.753;2.436]
$Q(\tau=10)$	[1.956;2.447]	[1.731;2.012]	[1.412;2.188]	[1.739;2.509]	[3.119;3.615]	[2.035;2.920]	[1.804;2.497]
$Q(\tau=100)$	[2.168;2.697]	[1.866;2.163]	[1.597;2.512]	[1.843;2.716]	[3.411;3.931]	[2.194;3.114]	[1.983;2.713]
Population	[2.153;2.785]	[1.890;2.219]	[1.502;2.352]	[1.831;2.650]	[3.418;4.082]	[2.145;3.247]	[1.942;2.817]

Note: $Q(\tau=i)$ is the total number of potential consumers computed as the average annual shipments of PC in a given country times the market size factor τ which takes the value *i*.

Table XIII: Confidence intervals at the 95% level for the simulated Nash monopoly price of DOS/WIN

Market size	Canada	France	Germany	Italy	Japan	UK	US
$Q(\tau=2)$	[629;698]	[575;638]	[576;647]	[530;597]	[586;665]	[580;651]	[583;671]
$Q(\tau=3)$	[590;651]	[562;618]	[566;628]	[530;593]	[562;631]	[569;634]	[559;635]
$Q(\tau=4)$	[567;625]	[548;602]	[552;611]	[523;583]	[546;.610]	[554;.617]	[543;.613]
$Q(\tau=5)$	[554;611]	[540;593]	[544;603]	[519;577]	[537;599]	[546;608]	[535;602]
$Q(\tau=6)$	[546;603]	[535;587]	[540;597]	[516;574]	[531;592]	[541;603]	[529;595]
$Q(\tau=8)$	[537;593]	[529;581]	[534;590]	[513;569]	[525;584]	[535;596]	[523;586]
$Q(\tau=10)$	[532;587]	[525;577]	[530;587]	[511;567]	[521;579]	[531;592]	[519;582]
$Q(\tau=100)$	[514;568]	[513;564]	[519;574]	[504;558]	[508;564]	[519;579]	[506;566]
Population	[507;560]	[505;554]	[510;563]	[497;550]	[497;552]	[511;568]	[497;555]

Note: Prices are expressed in US $.

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FOOTNOTES

[1] See for instance Jorgenson [2001].

[2] Implicitly the OS price is fully passed on to consumers. The elasticity of demand for operating systems is $\varepsilon_w = \varepsilon\left(p_w / p\right)$ where p_w is the price of operating systems, p is the average price of PCs and ε is the aggregate elasticity for PCs.

[3] Formally, in a setting with homogenous products, the profit-maximizing monopoly price of Windows, p_w, satisfies $p_w = -\left(p/\varepsilon\right) - r$, where p is the average price of PCs, ε is the aggregate elasticity for Intel-compatible PCs and r represents complementary revenues. For Reddy *et al.* [1999], $p = \$2000$, $\varepsilon \approx -2$ and $r = \$100$. See also Schmalensee [1999].

[4] For Fisher [1999], $p = \$1000$, $\varepsilon \approx -4$ and $r = \$160$.

[5] This intuition is supported by the high variability of prices in a given market and a given period. (See below Table VI.)

[6] 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].

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

[8] 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.

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

[10] 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.

[11] 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 (…)."

[12] 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 are rare for the home segment over the time period considered here.

[13] A few vendors with negligible market shares also have sold Macintosh clones. They are considered as competitors of Apple within this platform.

[14] See the Journal's editorial Web site that provides, in Appendix A of our supplemental document, a series tables and figures to complement this descriptive analysis.

[15] 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. Consequently this vendor should be de facto in the top 10.

[16] See the Journal's editorial Web site where the entry/exit process of the different generations of Intel processors is documented in Appendix A of our supplemental document.

[17] Unfortunately the shipments of MacOS-type computers are not broken down according to the different speeds of the PowerPC microprocessor.

[18] The type of processor is not a dimension describing the choice of platform. The choice of a processor speed does not reveal anything about the activities of the household. It is a technical feature that evolves over time independently of consumer choice, modifying the desirability and cost of the machine. An explicit account of this choice would allow for a case where consumers substitute more between Pentiums than between a Pentium and a 486 for instance. It is not feasible. As we notice in the descriptive analysis, 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 and the same quarter. The differentiation in terms of processor type would only be meaningful in a more dynamic structure. Here the processor type is an attribute of the choice.

[19] See the Journal's editorial Web site for a presentation of the demand system in Appendix B of our supplemental document.

[20] See the Journal's editorial Web site for the formulas of elasticities in Appendix C of our supplemental document.

[21] The technology exhibits constant returns to scale. We 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 drastically. The estimated returns were always slightly increasing, which looks reasonable for the PC manufacturing industry. Nonetheless we believe that analyzing this question requires a richer data set on costs for building meaningful cost functions at the firm level in this industry.

[22] Here we consider producer prices, i.e., net of the cost of OS. The difference between producer and consumer prices is only made when it is explicitly required.

[23] See the Journal's editorial Web site for a detailed presentation of the generic firm's program in Appendix D of our supplemental document. Our expression of markups permits to apply standard estimation procedures of nonlinear models proposed in econometric softwares like the procedure MODEL of SAS. Note that we generalize the simplified expressions presented by Verboven (1996).

[24] An alternative approach suggested by a referee would be to introduce a random effect in the utility associated with the outside good. Given the computational cost of this more general model, it is left for further research.

[25] 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.

[26] Results from the other experiments are available upon request. Moreover Table VIII does not present all the cross-effects that we consider. The cross-effects between countries and firms are provided on the Journal's editorial Web site in Appendix E of our supplemental document.

[27] We owe this remark to an anonymous referee.

[28] This appraisal on our results from the nested-logit model is similar to other critical assessments of this type of model. See for instance Hausman and Leonard [1997] and Slade [2001].

[29] The marketing practices of Microsoft during the 90's are detailed in an article published by Harvard Business School, 1999.

[30] Two other situations have been considered. First, we assume that computer manufacturers pass on exactly 100 percent of all price increases for DOS/WIN without reacting and then we look for the unilateral static monopoly price of DOS/WIN. The other situation corresponds to Microsoft being a leader in price while the OEM's producers are followers. In both cases we do not obtain very different results.

[31] However the computation requires some care because of the implicit form of Equations (6) and (17). See the Journal's editorial Web site for the computation of confidence intervals for OS prices in Appendix F of our supplemental document.

[32] Taking into account these complementary revenues is equivalent to assuming negative marginal costs for producing DOS/WIN. These complementary revenues are just creating a translatory movement of marginal costs downward. They are clearly not sufficient to fill the gap between the actual price of Windows and its static profit maximizing value.

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

[34] Note also that Werden (in his examples) and Reddy *et al.* [1999] use demands with constant elasticities, which is not the case here. Note that Reddy *et al.* [2001a] use semi-log demands and obtain similar results as in their 1999 article.

[35] The discussion is linked to one of the main roles provided by a computer operating system. Indeed an OS provides services to software applications – known as application programming interface – that makes application writing easier and more efficient. 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. 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].

[36] 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.