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INTRODUCTION (1)

The first personal computer (PC) recently celebrated its 20th anniversary, while the initial commercialisation of its forerunner, the microprocessor, was over 26 years ago. Laptop computers, for their part, appeared in 1984. Throughout this period personal computers have undergone enormous change. The increase in processing power has been marked by the growth of the semiconductor industry, whereby such power has doubled approximately every 18 months. The other components of personal computers (hard disk, memory, monitor, graphics card, programs, etc.) have also improved spectacularly. The increase in personal computer attributes has run in parallel to their cost becoming cheaper. This has been propitious to their incorporation into all realms of society. Spanish households, for instance, are beginning to view the computer as just another household electrical application. Indeed, according to media survey findings (Encuesta General de Medios), almost one-third of Spanish households had a computer at the end of 2000.

By definition, a price index should compare the prices of a single product at two moments in time, i.e. if characteristics (quality) have changed between both moments then an adjustment taking this into account should be made. Since 1985 the US statistics office has been using hedonic methodology to calculate computer industry quality-adjusted price indices, and a wealth of academic studies – applied mainly to the US case – have calculated these types of price indices (2). Although this methodology was initially applied in other industries (3), the intense technological progress in the computer industry means that this methodology is particularly suitable, and this has given rise to significant differences

(1) We wish to thank SEDISI for the data they provided; without them this paper could not have been written. We are also thankful to O. Bover, J.J. Camio, P. L'Hotellerie and those present at the Banco de España Research Department's internal seminar for their comments.

(2) See Bover and Izquierdo (2001).

(3) In the car industry Court (1939) calculates hedonic price indices for the United States for the period 1925-1935, and the US statistics office has been using hedonic methodology in the calculation of housing prices since 1968.

between PC price series adjusted with hedonic methodology and those estimated using more traditional techniques. Hedonic price indices show annual average falls of between 20 % and 40 %, depending on the type of product and on the period considered, while in those countries that use more traditional techniques, price falls are very small and price increases are even observed. These results have prompted a debate on the effects of the use of this methodology in the United States [see, for example, Landefeld and Grimm (2000)], and on its application in other countries. Currently, Eurostat [see Eurostat (1999)] recommends using hedonic methodology to construct computer price indices, and the statistical offices of Canada, Denmark, France and Sweden, to name a few, have already adopted it.

The aim of the study is to apply hedonic methodology to the Spanish case and to quantify the scale of the quality bias present in the official series of Spanish computer prices owing to an insufficient adjustment for past quality improvements. This methodology requires that an hedonic function be estimated, relating the price of a product to the level of its characteristics, so as subsequently to define on the basis of this estimation the price indices that represent changes in prices at a constant quality level. The most frequent obstacle this type of study usually faces is the absence of a database with the necessary information. In addition to the price of the good, to calculate hedonic price indices information is needed on all of the relevant characteristics – from the standpoint of both the producer and the consumer – that affect price formation. Specific technical knowledge is thus needed so as to be able to select these variables and data sources wherever they may be available. The database used in this study has been designed and provided by experts from the SEDISI (Spanish Association of Computer Sector Companies), and contains information for desktop and laptop computers between 1990 and 2000. In particular, data are available on computer price, manufacturer or distributor brand, processor speed, hard disk capacity, the amount of random access memory (RAM), CD-ROM availability (in the case of desktop computers) and weight (in the case of laptop computers). These are the variables that have been most frequently used in studies conducted for the United States. That is to say, they are all fundamental. It would nonetheless have been desirable to have other characteristics, such as the type of screen, the type of processor and the various computer accessories available. These, too, have undoubtedly improved substantially in recent years and should therefore be taken into account when analysing computer price movements.

After estimating the hedonic function, what is called an hedonic price index is constructed. This represents the course of computer prices once the significant changes in the characteristics (quality) of computers over this period have been hedonically controlled. This hedonic index is compared with the official series of computer prices published by INE (the Spanish National Statistics Office) to quantify the scale of quality bias in the prices of this industry in the Spanish economy.

The rest of the study is in five chapters. The first is a brief review of the methodology that is to be used, referring both to the specification of the hedonic function and the subsequent calculation of the price indices. The second chapter describes in detail the characteristics of the database used, while the third chapter presents the estimations of the hedonic function. The fourth chapter constructs various hedonic price indices based on the estimations made in the third chapter. Here the prices for desktop and laptop computers are aggregated in a common computer index, which is compared with the official price index calculated by INE in order to quantify the quality bias present in the latter index. The fifth and final chapter draws the main conclusions.

I

HEDONIC METHODOLOGY

This chapter briefly presents the essential aspects of hedonic methodology that are to be applied in the subsequent chapters of this study, referring both to the specification and estimation of the hedonic function, which links product prices and characteristics, and to the subsequent construction of the hedonic price indices (1).

I.1. Hedonic functions

Hedonic methodology assumes that the observed price of a product is a function of its characteristics. Various functional forms have been applied for the price of computers, although it is the linear, semi-logarithmic and double logarithmic forms that are most frequently used (2).

In a double logarithmic specification the relationship between prices and their characteristics is as follows:

$$\ln P_{it} = \alpha_0 + \sum_{t=1}^{T} \delta_t D_t + \sum_{j=1}^{n} \beta_j \ln X_{ijt} + u_{it} \qquad t = 0, \ldots T, \qquad [I.1]$$

where P_{it} is the price of the model i in period t; D_t is a time dummy variable that takes the value one in period t and zero in the other periods; X_{ijt}

(1) An extensive review of hedonic methodology for the computer sector can be found in Triplett (2000). Further details can be had in the works cited subsequently in this chapter.

(2) Another more flexible functional form which is occasionally used is the translog. However, there are many other possibilities to make the relationship between prices and characteristics more flexible: these include the semi-logarithmic square form, which can be seen along with the translog in Diewert (2001), or those estimated by Nelson et al. (1994) to allow the effect of the characteristics to vary over time.

is the level of characteristic j in model i in period t; and u_{it} is an error component.

The other two functional forms only differ from equation [I.1] in the transformation with which the prices and characteristics appear. In a linear form, both prices and characteristics are related in levels, while when the functional form is semi-logarithmic, the logarithm of the prices is a function of the levels of the characteristics. Although a double logarithmic specification is used, if some of the characteristics have the value zero or if dummy variables are used to capture the presence or absence of a characteristic, logarithms cannot be applied to these variables and, consequently, these variables are entered in semi-logarithmic form (3).

Note that to avoid collinearity between the constant and the time dummy variables, the dummy variable for the first period has been eliminated. Consequently, the δ_t are in relative terms at the initial period and, therefore, they provide the change, between period and the initial period, in the estimated price when changes in characteristics are controlled. Each β_j in equation [I.1] is the shadow price of the related characteristic j. Lastly, the u_{it} show effects as varied as those due to measurement errors of the variables included, to omitted characteristics or to an incorrect specification of the functional form.

From Rosen (1974) up to the latest paper by Diewert (2001), various theoretical studies have been conducted to determine the functional form. However, as Triplett (2000) indicates, neither the classical theory of utility nor the theory of production can specify the type of relationship between the prices and characteristics of a product. Consequently, this aspect is an empirical matter. Table 4.2 of Triplett (1989) and Table 5.3 of Triplett (2000) provide a broad but not complete view of the various functional forms that have been used for computers in the literature. As can be seen from both tables, the double logarithmic form is that which has been most used, but this choice is not always backed by a test against other specifications (4) [see also Table 4.3 in Triplett (1989)].

When estimating an equation such as [I.1] there are several non-excluding strategies. Firstly, the entire sample available can be used to estimate a single regression (estimation with the entire data pool). In this way, it is imposed that the parameters β_j are constant over time. When

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(3) However, this is not the only reason for mixing variables in levels and in logarithms. Indeed, there is no justification requiring that the same transformation be applied to all the variables. In this respect, and following a statistical analysis, the Institut National de la Statistique et des Études Économiques [see Moreau (1996)] uses both variables in levels and in logarithms to explain the logarithm of the computer price index.

(4) In order statistically to compare alternative functional forms, it is usual to resort to the or F test and, albeit more sporadically, the Box-Cox transformation is also used.

significant technological innovations occur, this restriction may be rather unrealistic. The second possibility softens (5) this limitation by breaking down the data pool into adjacent periods (two or more), estimating a series of regressions. In each of the regressions, except in the first, the first period considered is the last included in the previous regression. This strategy holds the coefficients of the characteristics constant in each of the adjacent periods, but it allows them to change between the different regressions. Evidently, both strategies can be followed, testing for the most appropriate and the optimal length of the adjacent periods. Another even simpler means of allowing the β_j coefficients to vary over time consists of estimating separately an equation for each of the T+1 periods of the sample. In this case, time variability and, consequently, the D_t disappear in each equation.

To conclude this section, a brief reference should be made to the three main arguments usually brandished by the detractors of hedonic regressions. Firstly, researchers frequently do not have transaction prices but list prices. Insofar as discounts are a widespread practice, as is the case with computers, the resulting price change measurements will be biased if the discounts vary over time. Generally, obtaining information on discounts is complicated for several reasons. As Baldwin *et al.* (1997) point out, it is on one hand customary for block discounts to be applied to the joint purchase of computers and other accessories, making it difficult to distinguish the portion of the discount that relates to each product. Furthermore, in granting discounts sellers discriminate between purchasers on the basis of their expectations about future purchases of equipment and services.

The second problem is that of multicollinearity. It is well-known that if there is correlation between the characteristics, the estimated coefficients are unstable and their variance very high. Consequently, the economic interpretation of the $\hat{\beta}_j$ (the symbol ^ over a coefficient indicates that it is the estimated value) suffers, although this need not invalidate the estimation of the quality-adjusted prices resulting from the hedonic regression.

Finally, there is the problem of the omission of relevant characteristics. In this respect, a distinction must be made between three different situations. In the first, the variable omitted is not correlated with those included, whereby the $\hat{\beta}_j$ are unbiased and their economic interpretation as a shadow price of characteristic j is valid. However, the $\hat{\delta}_j$ are biased and the same occurs with the quality-adjusted prices that can be obtained from this equation, in that it is not possible in these prices to control for part of the

(5) Nonetheless, this is not the only means for allowing the parameters to vary over time. There are non-linear models in the parameters such as those estimated in Nelson et al. (1994) which combine the joint estimation of the entire period with time-dependent parameters.

changes in the characteristics (those relating to the omitted variable). In the second situation, the omitted variable is correlated with one or more of the variables included and both vary simultaneously and by the same proportion. In these circumstances, although the related $\hat{\beta}_j$ is biased, the $\hat{\delta}_j$ and the quality-adjusted prices are unbiased. However, in the third situation, when the omitted variable does not move in synchrony with that with which it is correlated, even the $\hat{\delta}_j$ and the quality-adjusted prices are biased.

Rather than invalidating hedonic regressions, these problems emphasise the need, first, to make a sound selection of the variables, in which connection knowledge of the product is essential; and, further, to spare no effort in obtaining a sample that measures prices and characteristics appropriately. This intensive requirement of hedonic methodology for information, both in quality and quantity, is perhaps the key obstacle to greater use of this methodology by more statistical offices.

I.2. Price indices

There are several procedures for calculating quality-adjusted price indices on the basis of hedonic regressions. The simplest is the so-called time dummy variables method. Under this procedure, the quality-adjusted price index is calculated drawing on the $\hat{\delta}_j$ coefficients estimated in an equation such as [I.1]. The specific expression of the index depends on the functional form of the regression and on the estimation strategy. When estimation is with the entire data pool and the functional form is double logarithmic or semi-logarithmic, the $\hat{\delta}_j$ represent the percentage change in the price controlling for changes in characteristics between the period t and the initial period. Consequently, the index is constructed on the basis of the sequence of $\exp(\hat{\delta}_1)$, $\exp(\hat{\delta}_2)$, etc. (6). If an adjacent-peri-

(6) Note that for the double logarithmic form, the quality-adjusted price index in period t based on the initial period and in basis points would be:

$$I_{0t} = \frac{E\left[\exp\left(\ln P_t - \sum_{j=1}^{n} \beta_j \ln X_{jt}\right)\right]}{E\left[\exp\left(\ln P_0 - \sum_{j=1}^{n} \beta_j \ln X_{j0}\right)\right]},$$

where E is the mathematical expectation. Therefore, in calculating it on the basis of the sequence of the $\exp(\hat{\delta}_t)$, the exact index is not being computed, only an approximation. This is because it is well known that $\exp(\hat{\delta}_t)$ is a biased estimator of the estimator of $\exp(\delta_t)$. The bias is corrected by using

$$\exp \hat{\delta}_t + \frac{1}{2}\hat{\sigma}_t^2,$$

where $\hat{\sigma}_t$ is the estimated variance of δ_t. Nonetheless, this correction is usually avoided in practice, given its minor value.

ods estimation is performed, it should be borne in mind that the $\hat{\delta}_j$ are now no longer all in relation to the initial period but to the first period in each of the sub-samples estimated. Hence if, for example, each sub-sample is made up of two adjacent periods from the pool, the index in period based on the initial period would be equal to (7):

$$I_{0t} = \exp\left(\sum_{k=1}^{t} \hat{\delta}_k\right). \qquad [I.2]$$

When period-by-period estimations are made, the $\hat{\beta}_j$ coefficients vary over time, whereby the foregoing procedure is no longer valid (8). In their absence, an index of prices of characteristics can be calculated in which, for example, the amounts are fixed in the base year, i.e. a Laspeyres-type index (9). If the functional form is double logarithmic, this index is obtained from the following expression:

$$I_{0t} = \frac{\exp\left(\hat{\alpha}_t + \sum_{j=1}^{n} \hat{\beta}_{jt} \overline{\ln X_{j0}}\right)}{\exp\left(\hat{\alpha}_0 + \sum_{j=1}^{n} \hat{\beta}_{j0} \overline{\ln X_{j0}}\right)}, \qquad [I.3]$$

where $\overline{\ln X_{j0}}$ is the average value of characteristic j in the base year. Similar expressions are obtained for the other two functional forms. Nonetheless, if the characteristics undergo significant changes from one period to another, it is advisable to use an index, for instance a chained Laspeyres index, in which the characteristics are not fixed. In that case the index is calculated as:

$$I_{0t} = I_{01}\, I_{12} \ldots I_{t-1t} \qquad t = 1, \ldots T, \qquad [I.4]$$

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(7) When the functional form is linear, and estimated with the entire sample, the index is calculated as:

$$I_{0t} = \frac{\hat{\alpha} + \ddot{\delta}_t}{\hat{\alpha}}.$$

However, if adjacent periods are estimated, for instance, taking the periods two by two, the expression for calculating the index is now:

$$I_{0t} = \frac{\hat{\alpha} + \sum_{k=1}^{t} \hat{\delta}_k}{\hat{\alpha}}.$$

(8) Although the $\hat{\beta}_j$ are also allowed to vary over time in adjacent-period estimation, they nevertheless hold constant in each set of periods included in each regression and, therefore, the δ_t coefficients continue to provide the estimation of quality-adjusted inflation.

(9) Indices of other types (e.g. Paasche or Fisher indices) can also be calculated.

where

$$I_{k-1k} = \frac{\exp\left(\hat{\alpha}_k + \sum_{j=1}^{n} \hat{\beta}_{jk} \overline{\ln X_{jk-1}}\right)}{\exp\left(\hat{\alpha}_{k-1} + \sum_{j=1}^{n} \hat{\beta}_{jk-1} \overline{\ln X_{jk-1}}\right)}. \qquad [I.5]$$

In principle, the hedonic regression assigns the same importance to all the observations of the sample, which in turn makes for potential bias in the indices calculated with the time dummy variables method. Ideally, information would be available on sales in order to estimate by weighted least squares, in accordance with the amounts sold. The influence of relatively unrepresentative market prices would thereby be reduced and, therefore, better measures of quality-adjusted prices could be estimated. As Triplett (1989) indicates, using the characteristics-price-index method it is easy to add weights to the indices without having to estimate a weighted regression, simply taking the weighted measures of the characteristics when calculating the price index (10). In any event, on many occasions information on sales is unfortunately not available. Accordingly, if it is generally thought that the best-selling computers are those with a better price-quality ratio, the resulting index will overstate the true quality-adjusted prices.

(10) The price imputation method has the same property. In connection with this method see, for example, Aizcorbe et al. (2000), Triplett (1989) or Triplett (2000).

II

DATABASE

This study has been performed using a database provided by SEDISI with prices and characteristics for desktop and laptop computers for the period 1990-2000. For desktop computers there is information on the price of the computer, the brand (manufacturer or distributor), processing speed measured in megahertz (MHz), the amount of RAM and the computer's hard disk capacity, both measured in megabytes (Mb), and the availability of CD-ROM. The same information is available in the sample of laptop computers, with the exception of that relating to CD-ROM, although in this case there is information on the weight of the computer in kilograms.

The database has been compiled with information provided by distributors. Consequently, it is representative of sales to households, since firms usually buy directly from manufacturers. After consulting the distributors the sample was made up with the replies received, which in many cases depended on whether the distributor had compiled the information or not. The case might arise where a single distributor could only provide information for certain years which are not necessarily consecutive. Both the price(1) and the characteristics correspond to those of the computers sold by the distributors in the related year. Generally, information on several computer models is available for each brand. The sample is made up of annual cross-section sub-samples, and it is therefore lacking a panel structure that would allow the price of the same computer to be tracked for consecutive periods. In other words, there is only one annual observation for each computer. The choice of available variables has been made by the SEDISI experts, who consider that such variables provide the pertinent information for explaining changes in computer prices in Spain over this period. The characteristics of this sample make it similar to those

(1) The price is the average price at which the distributor sells a computer, including the monitor and any other incorporated accessory.

used in various hedonic studies conducted for the US computer market [see, for instance, Berndt and Rappaport (2001), Nelson et al. (1994) or the compilation in this connection offered in Triplett (2000) in table 5.2]. The variables that these studies consider essential for determining the price of a computer are available, although information is lacking on the set of accessories the computer has (type of monitor and keyboard, modem, software, etc.) and which may be relevant. Clearly, the amount and quality of these accessories has been increasing over the sample period; consequently, their omission would, in any event, prompt a cautious estimate of inflation adjusted for changes in quality. Regrettably, there is no information on the number of units of each computer sold. Therefore, aggregation will always be by means of the simple average of the sample observations. Once again, this circumstance may give rise to a conservative adjustment of prices for changes in quality.

For desktop computers, 132 observations per year are available on average, with the low standing at 67 observations in 1992 and the high at 246 in 1999. In some cases, in approximately half the sample, it has been possible to obtain information on the type of processor (286, 386, 486, Pentium, etc.) on the basis of the name of the computer model. Later, it will be seen how this information may be relevant, although the fact this characteristic is confined to half the sample means a sufficiently detailed analysis cannot be conducted.

A notable characteristic of the sample is its distribution by brand. It appears that the different rate of response has given rise to a majority presence of what are known as cloned computers, i.e. computers assembled by distributors who put their name to them as opposed to computer-manufacturer brands. For the period as a whole, observations for 190 different brands are available. Except in 1999, when brand computers accounted for over half the sample, the proportion of cloned computers was in excess of 80 % of the total sample (2). Although, generally, price trends do not appear to differ between brand and cloned computers, the special representation of the latter in the sample available should be borne in mind when interpreting the results of this study.

An initial observation of the changes in average characteristics during the period highlights most significant quality improvements in the average computer in the sample. While an average computer sold in 1990 had a

(2) In addition to few brand computers being available, their presence is very disperse and very few observations are available for the same brand in successive periods. It will later be seen how this hampers estimation of brand dummy variables along with time dummy variables, at least for adjacent-period estimations. Table A.1 in the Appendix details the computer brands identified as desktop computer manufacturers. All computers belonging to any of these brands have been called brand computers.

processing speed of MHz 26, 1.8 Mb of RAM and 120 Mb of physical space on the hard disk, and no CD-ROM, in the year 2000 average processing speed has multiplied more than thirtyfold, up to 800 MHz, RAM has increased more than fifty-fold to 93 Mb, and hard disk capacity has been multiplied by more than 140, exceeding 17,000 Mb. As to CD-ROM, it is present in all computers in 2000. However, despite the spectacular increases in computer characteristics (3), the average price of computers sold in 2000 is a quarter of the 1990 price. That is to say, the average price has fallen by close to 13 % per year. This initial observation of the data already points to significant falls in computer prices, even before controlling for the enormous changes in the characteristics that they incorporate. The hedonic methodology used in the following chapters will enable the course of these prices to be estimated when an adjustment is made for the above-mentioned quality changes.

Chart II.1 shows the time profile of both quality improvements and prices, represented by their annual increases. It can be seen how in virtually each year of the sample there have been significant improvements in the average quality of computers accompanied by price falls. Nonetheless, between 1994 and 1996 and in 1998 and 1999 price increases in relation to the previous year were observed. In each of these years, except in 1999, these rises were accompanied by increases in the average characteristics of computers, whereas in 1999 it appears that the greater presence of brand computers prompted both a price increase in relation to 1998 and a decline in the average characteristics present in computers. Clearly, then, it will be important in the estimations to control for the different brand-based annual distribution of the computers in the sample. Lastly, there appear to have been greater falls in average price in the first half of the nineties, while in the second half of the decade the declines were on a lesser scale or, indeed, price increases took place. However, it is precisely in this sub-period when the biggest increases in the average quality of computers were observed. Consequently, the quality-adjusted price index will probably not show this profile.

As regards laptop computers, the sample available is somewhat smaller and consists of an average of 67 observations per year, with a low of 44 in 1992 and a high of 98 in 1999. As discussed, the weight of the computer is available. However, this variable exhibits missing values in a total of 180 observations, which restricts its use in the estimations.

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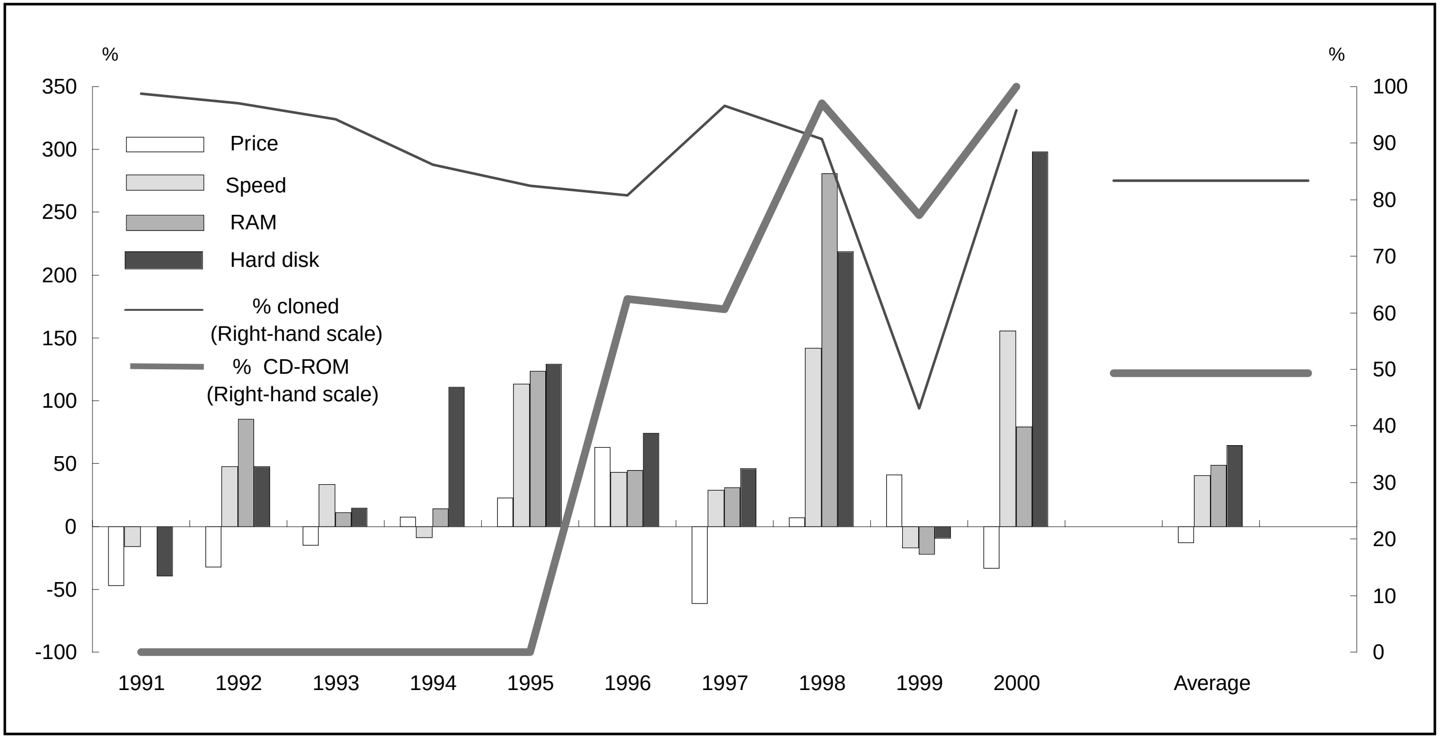
(3) These data reflect perhaps only a portion of the gains in average computer quality over this period. From the information on the type of processor, it is known that computers in 1990 had a 386 processor, while in 2000 they are all Pentium. Further, there is no information on the incorporation into current computers of multimedia characteristics (sound and images), which were non-existent ten years back, and of accessories such as the modem or type of monitor.

CHART II.1

CHANGES IN THE CHARACTERISTICS OF DESKTOP COMPUTERS (a)

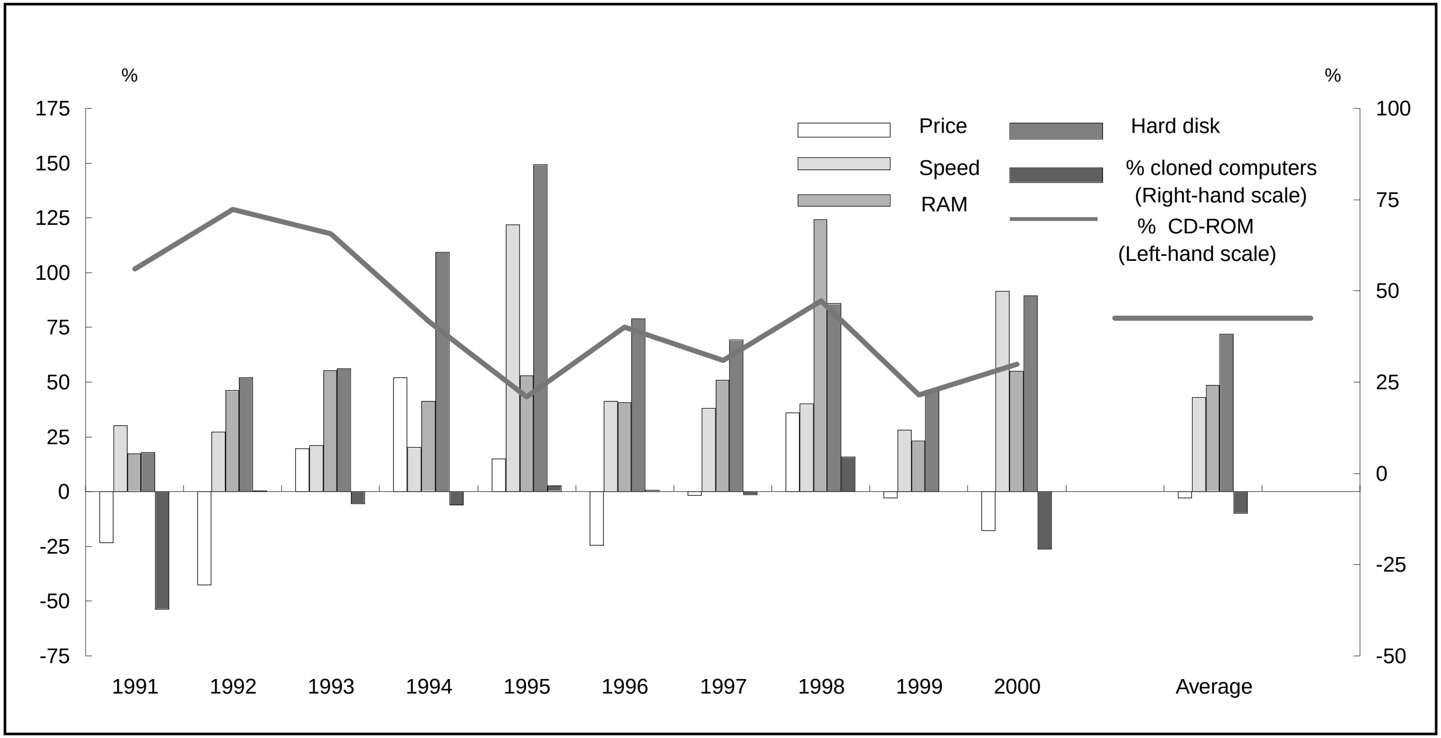


Source: Banco de España.

(a) Year-on-year rates of change, except for CD-ROM and cloned. For the latter, the proprotion of computers with this characteristic is depicted.

CHART II.2

CHANGES IN THE CHARACTERISTICS OF LAPTOP COMPUTERS (a)



Source: Banco de España.

(a) Year-on-year rate of change, except for cloned computers. For the latter, the proportion of computers with this characteristic is depicted.

This is particularly important in the years 1996, 1997 and 2000; if the information on the computers for which the weight is not available is discarded, the number of observations falls to less than 20. In 1992 and 1998 the observations also fall significantly (to 34 and 36, respectively), whereas the situation is much less important in 1999, when despite there being 20 computers without their weight, 78 do have it. In the remaining years, the weight for all the computers in the sample is available. Unlike in the desktop computer sample, in this case the presence of brand computers is far greater (4). On average, for the eleven years, 57 % of computers have been identified as brand makes and, from 1995, the proportion of this type of computer varies between 60 % and 80 % of the total. This greater presence translates, in turn, into the availability of observations for consecutive years of computers of the same brand, enabling an estimation of quality-adjusted inflation to be made while controlling for the effects of the brand. Nonetheless, the information on the type of processor is very scant, and in some years this characteristic is unknown in all the computers.

As earlier, an initial observation of the changes in the average characteristics of laptop computers sold during the study period indicates most sizeable increases in average quality. As in the case of desktop computers, the average characteristics of a computer in the year 2000 are spectacularly superior to those present in a 1990 computer. Average processing speed has multiplied more than thirty-fivefold between 1990 and 2000, RAM more than fiftyfold and hard disk capacity more than two-hundredfold. As to weight, an average computer sold in 2000 weighs little more than one third of what it did in 1990. All this has happened while the average price in 2000 is 25 % less than the average price in 1990, i.e. an annual decline of 3 % in average price is observed, a figure notably below that for desktop computers (5). The time profile of quality improvements and changes in prices can be seen in Chart II.2. This chart shows that quality improvements are constant throughout the entire period. The average characteristics of computers (speed, RAM and hard disk capacity) increase in all the periods, while there are – albeit less widespread – falls in average weight (6). Prices show most significant declines in 1991, 1992, 1996 and 2000, while in the remaining years the falls are smaller or price increases occur.

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(4) Table A.2 in the Appendix lists the computer brands identified as manufacturer brands.

(5) This lesser decline in prices is not due to a greater presence of brand-name computers in this sample. Among laptop computers, price falls between 1990 and 2000 are very similar for cloned computers (-3.4%) and brand computers (-3.1%).

(6) This variable shows missing values in an appreciable part of the sample, which may affect the calculation of these annual average values.

III

ESTIMATIONS OF THE HEDONIC FUNCTION

Desktop and laptop computers are products that may be considered as different, since they provide different services. Consequently, the implicit prices of the characteristics of both products need not coincide. In this connection, Berndt and Rappaport (2001), drawing on a set of characteristics like that used in this study, but with data for the United States, conclude that the relationship between the prices of these two types of computers and their characteristics is not the same. Indeed, in the literature independent regressions are usually constructed for each type of computer, as, for instance, the Bureau of Labor Statistics (BLS) [see Holdway (2000)] or the Institut National de la Statistique et des Études Économiques (INSEE) [see Moreau (1996)] do. Accordingly, in this study separate analyses have been conducted for desktop and laptop computers.

As discussed in the first chapter, an empirical approach has been adopted for selecting the functional form of the hedonic function, testing which form offers a better approximation to the behaviour of the data. The specifications most used in studies on computers have been considered, namely the linear, semi-logarithmic and double logarithmic specifications. Nonetheless, such high estimated price falls are obtained with the linear specification that the price index constructed lacks economic meaning, as it takes negative values. Consequently, this specification has been ruled out, and here only the results with the other two functional forms are given.

For both specifications, the initial step was the joint estimation of [I.1] for the entire period under study. These estimations assume that the implicit prices of the characteristics, the $\hat{\beta}_j$ estimated coefficients, hold constant over time. As highlighted in the previous chapter, during the eleven years in the sample, the changes in the characteristics present in an average computer have been very high, making it very risky to assume that implicit prices have not changed. In this respect, Berndt and Rappaport (2001) find for the United States that the coefficients of the characteristics differ annually from 1987 in the hedonic regressions for the prices of desktop computers, and from 1993 in those for laptop prices. Consequently, the estimations with constant $\hat{\beta}_j$ should be interpreted as an initial approximation to the estimation of the hedonic function. Next, this assumption is relaxed to allow time variation in the implicit prices of the characteristics, on estimating for adjacent periods. Finally, regressions have been estimated for each of the years in the sample. In all cases, estimation has been via unweighted ordinary least squares since no information is available in the database on the number of units of each model sold.

III.1. Desktop computers

This section presents the different estimations obtained for desktop computers. Table III.1 offers the results of the estimation with the entire data pool of an equation like [I.1] under the semi-logarithmic specification of the hedonic function. The first column corresponds to an estimation for the entire sample, for both brand and cloned computers, in which a dummy variable has been included for each of the brands present in the sample. This variable includes aspects related to the brand (prestige, guarantee, etc.) not observed in the sample available. The same estimation has been repeated in the second column without including this set of brand dummy variables. The following two columns show the results of an estimation confined to the set of so-called cloned computers in the sample. This type of computer accounts for more than 80 % of the total sample (1210 of the 1452 observations) and, moreover, the presence of brand computers is highly concentrated in certain years, especially in 1999. It thus seems appropriate to make some estimations without these brand computers. Once again, in this case two estimations are provided, the first of which includes a dummy variable for each of the brands, the second not. Lastly, the fifth column offers an estimation for all those computers in the sample for which information is available on the type of processor they incorporate (286, 386, 486, Pentium I, II and III, Celeron and AMD one). In this case the sample is limited to half the total observations and a dummy variable has been included for each type of processor (1).

A high explanatory power of the variables included in the regression is observed. When brand dummy variables are included in the regression, the adjusted R^2 hovers around 70 %, falling to 50 % when the dum-

(1) Excluding the 286 processor taken as a reference.

TABLE III.1

HEDONIC REGRESSIONS FOR DESKTOP COMPUTERS WITH SEMI-LOGARITHMIC SPECIFICATION.
JOINT ESTIMATION FOR THE PERIOD 1990-2000

	1	2	3	4	5
Speed	0.0007	0.0007	0.0017	0.0014	0.0032
	(8.09)	(6.69)	(11.37)	(7.61)	(11.52)
RAM	0.0064	0.0066	0.0064	0.0066	0.0039
	(15.29)	(14.25)	(14.42)	(13.54)	(4.58)
Hard disk	0.000007	0.000002	0.000003	-0.000002	0.000004
	(2.41)	(0.64)	(1.29)	-(0.74)	(0.48)
CD-ROM	0.3627	0.3516	0.2490	0.2515	0.1673
	(9.69)	(8.96)	(5.67)	(5.60)	(3.67)
d-1991	-0.4237	-0.6146	-0.4245	-0.6069	-0.5499
	-(2.96)	-(9.64)	-(3.21)	-(10.17)	-(4.97)
d-1992	-0.6822	-0.8860	-0.6913	-0.8994	-0.9765
	-(5.68)	-(13.42)	-(6.26)	-(14.48)	-(11.31)
d-1993	-0.7064	-1.0666	-0.6703	-1.0754	-1.3944
	-(4.95)	-(17.17)	-(4.90)	-(18.28)	-(12.45)
d-1994	-0.7434	-0.9586	-0.7680	-0.9852	-1.5157
	-(5.55)	-(17.90)	-(6.11)	-(19.28)	-(14.02)
d-1995	-0.7649	-0.9937	-0.8815	-1.0929	-2.0603
	-(5.38)	-(16.12)	-(6.32)	-(18.00)	-(17.05)
d-1996	-0.8950	-1.0066	-1.0029	-1.0663	-2.4236
	-(6.26)	-(15.43)	-(7.17)	-(16.48)	-(18.84)
d-1997	-1.3084	-1.6590	-1.3910	-1.6737	-2.8680
	-(9.20)	-(25.74)	-(10.18)	-(25.94)	-(20.91)
d-1998	-1.8779	-2.2565	-2.1165	-2.3862	-3.5752
	-(12.80)	-(29.28)	-(14.65)	-(28.14)	-(18.88)
d-1999	-1.5793	-1.7193	-1.9932	-2.1148	-3.3608
	-(10.93)	-(25.01)	-(13.53)	-(27.12)	-(17.75)
d-2000	-2.3244	-2.7789	-2.9651	-3.1015	-4.5411
	-(13.84)	-(24.01)	-(16.11)	-(20.76)	-(11.80)
Constant	12.8528	13.1250	12.8230	13.1088	12.4106
	(104.00)	(286.89)	(112.38)	(305.86)	(133.59)
p-value brand	0.00	—	0.00	—	0.00
Type of processor	No	No	No	No	Yes
Sample	All	All	Cloned	Cloned	All
Observations	1452	1452	1210	1210	783
Adjusted R^2	0.6898	0.4685	0.7383	0.5355	0.8428
F(n, m)	47.86	92.34	51.08	100.56	49.18
	(14, 1248)	(14, 1437)	(14, 1019)	(14, 1195)	(21, 605)

Source: Banco de España.

mies are excluded. The results of the fifth column indicate that it would have been useful to have information on the type of processor for the entire sample, since in this case the adjusted R^2 exceeds 80 %. The estimation of the implicit prices of the characteristics gives the expected positive signs. The exception is the hard disk, which for one specification has a negative coefficient and in four of the five specifications shown it cannot be affirmed that this price is other than zero. The comparison between the estimation for the total sample and solely with cloned computers shows that it cannot be accepted that the implicit prices of the characteristics of both types of computer are the same (2). Moreover, the estimation of quality-adjusted cumulative inflation over the eleven years of the study differs according to the sample used, with a bigger price fall being obtained for the cloned sample. Lastly, the estimation of the time dummy variables shows a clearly declining profile in the price of computers when controlling for changes in characteristics. Only in 1999 was marked growth over the previous year observed in the coefficient associated with the dummy variable.

Table III.2 offers analogous information to Table III.1, changing the specification of the hedonic function to a double logarithmic one (3). It can be seen how, under this specification, a better fit is achieved. The adjusted R^2 are, at least, 60 %, rising to 80 % when the brand dummy variables are included or to over 90 % when the estimation is made considering the type of processor. This adjustment is similar to those obtained by other studies conducted for the US case [see Nelson *et al.* (1994) or Cole *et al.* (1986)], albeit somewhat lower than that obtained by the BLS in the hedonic regression used in the producer price index [see Holdway (2000)]. Under this double logarithmic specification, the problems previously detected in the estimation of the implicit price of the computer's hard disk capacity disappear. Now positive and significant coefficients are obtained for all the variables included in the regressions. Comparing the coefficients of columns 1 and 3 (or 2 and 4), it can be analysed to what extent the implicit prices of the characteristics differ according to whether brand or cloned computers are involved. Although the values estimated in both regressions are very similar, a test on the equality of coefficients between both types of computer is rejected for the coefficients of the four characteristics included in the regression. Nonetheless, the estimation of cumulative inflation over ten years, the coefficient of the time dummy variable for the year 2000, does not differ significantly from the sample with only cloned computers (columns 3 and 4) and the sample with all com-

(2) A test has been performed on the equality of the coefficients of each of the characteristics of both types of computer.

(3) In this specification the availability of CD-ROM is included as a dummy variable of zeros and ones; therefore, its logarithms are not taken.

TABLE III.2

HEDONIC REGRESSIONS FOR DESKTOP COMPUTERS WITH DOUBLE LOGARITHMIC SPECIFICATION.
JOINT ESTIMATION FOR THE PERIOD 1990-2000

	1	2	3	4	5
Speed	0.4762	0.2768	0.5249	0.3328	0.3786
	(17.65)	(7.73)	(20.73)	(9.21)	(16.84)
RAM	0.4050	0.4231	0.4146	0.4368	0.2592
	(21.87)	(18.79)	(24.73)	(20.43)	(12.77)
Hard disk	0.1378	0.1108	0.1275	0.0872	0.1979
	(8.29)	(5.06)	(8.61)	(4.18)	(11.95)
CD-ROM	0.2782	0.2249	0.1655	0.1073	0.1255
	(10.30)	(6.61)	(5.70)	(2.85)	(3.96)
d-1991	-0.4752	-0.5506	-0.4463	-0.5449	-0.5538
	-(4.62)	-(10.02)	-(5.13)	-(10.95)	-(7.24)
d-1992	-1.2950	-1.3210	-1.3148	-1.3548	-1.2884
	-(14.78)	-(22.62)	-(17.80)	-(25.39)	-(21.25)
d-1993	-1.5911	-1.5764	-1.4987	-1.5966	-1.6603
	-(15.09)	-(27.80)	-(16.24)	-(30.46)	-(21.19)
d-1994	-1.6768	-1.6464	-1.7380	-1.6908	-1.8028
	-(16.84)	-(31.36)	-(20.20)	-(34.11)	-(23.72)
d-1995	-2.3904	-2.2042	-2.4615	-2.3142	-2.7567
	-(21.39)	-(30.92)	-(24.41)	-(33.05)	-(30.85)
d-1996	-2.7721	-2.3867	-2.7962	-2.4421	-3.1717
	-(23.81)	-(29.57)	-(26.76)	-(30.94)	-(32.75)
d-1997	-3.4308	-3.2275	-3.4230	-3.2232	-3.8088
	-(28.80)	-(37.05)	-(32.46)	-(37.81)	-(36.46)
d-1998	-4.6176	-4.2082	-4.6089	-4.2337	-4.4569
	-(34.62)	-(37.47)	-(39.06)	-(38.27)	-(33.90)
d-1999	-4.3905	-3.6843	-4.5321	-3.9623	-4.2895
	-(32.97)	-(34.71)	-(37.89)	-(37.84)	-(32.50)
d-2000	-5.1714	-4.7320	-5.1846	-4.7506	-4.1485
	-(34.39)	-(34.28)	-(38.51)	-(34.57)	-(19.04)
Constant	10.8113	11.6606	10.6260	11.5785	10.7902
	(85.13)	(86.20)	(92.42)	(85.22)	(107.84)
p-value brand	0.00	—	0.00	—	0.00
Type of processor	No	No	No	No	Yes
Sample	All	All	Cloned	Cloned	All
Observations	1452	1452	1210	1210	783
Adjusted R^2	0.8398	0.6096	0.8868	0.6816	0.9249
F(n, m)	176.10	162.82	213.70	185.90	134.41
	(14, 1248)	(14, 1437)	(14, 1019)	(14, 1195)	(21, 605)

Source: Banco de España.

puters (columns 1 and 2). Lastly, a clearly diminishing profile can be observed in the time dummy variables, which is all the more marked in the case of the semi-logarithmic specification, the only exception, as was previously the case, being the increase in prices detected in 1999. In sum, these initial results appear to indicate a preference for the double logarithmic as opposed to the semi-logarithmic specification: the fit achieved is superior and the problems in the estimation of the implicit price of the hard disk disappear.

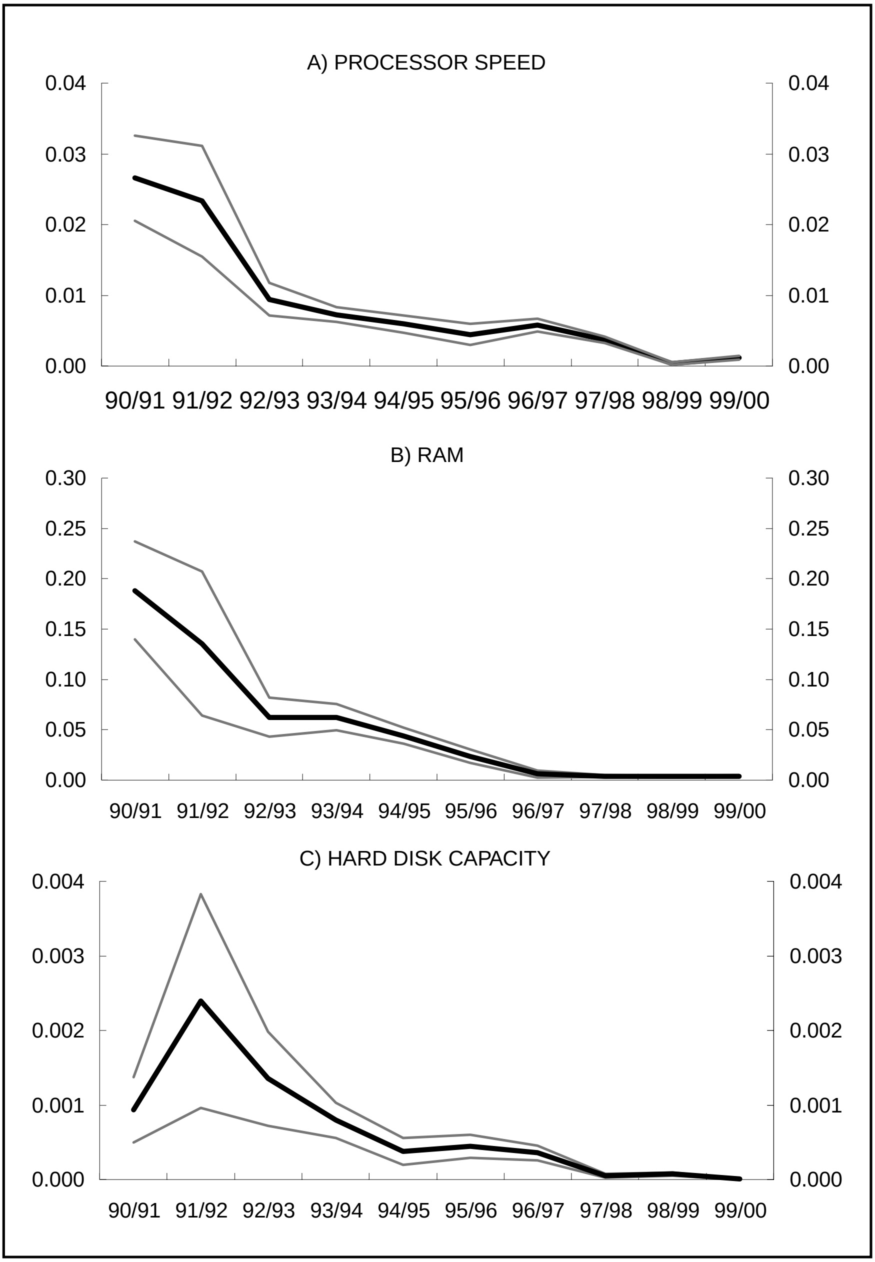
The foregoing estimations assume that the implicit prices of the characteristics have held constant over time. However, given the spectacular growth shown by the average characteristics present in the computers in the sample, this assumption should be relaxed to allow for time variation in the implicit prices of the computer's characteristics. One initial method would involve estimating the hedonic function separately for sets of adjacent periods. In this estimation, the prices of the characteristics vary from estimation to estimation, but they are constant for each pair (or set) of adjacent periods. Consequently, the estimation of quality-adjusted inflation stems, as before, from the related time dummy variables. The estimation has been made for pairs of adjacent periods.

A sample of the results obtained in these regressions for adjacent years is offered in Charts III.1 and III.2. They show the trend of the coefficients of the characteristics included in the regression, along with their confidence intervals of 95 %, for the different pairs of periods, in the case of the estimation made for the entire sample and including a dummy variable for each brand, for the semi-logarithmic and double logarithmic specifications, respectively. Clearly, imposing the restriction that these coefficients are constant over the whole of the period is not appropriate. In the case of the semi-logarithmic specification, the implicit prices of the characteristics are on a clearly diminishing trend throughout the period, while in the double logarithmic specification these prices show no clear trend. As earlier mentioned, these regressions for adjacent years have been made for consecutive periods of two years and it has been proven through Chow tests that the hypothesis of the stability of the parameters for any sub-period longer than two years does not hold.

Table III.3 presents the basic statistics for all adjacent-period estimations. The first four columns showed the results under the semi-logarithmic specification and the following four columns under the double logarithmic specification. In each case, the first two columns (1, 2 and 5, 6) give the results for the entire sample with a dummy variable for each brand in the first case and with none in the second. Columns 3 and 7 offer the results solely for the sample of cloned computers, it being impossible in this case to estimate a dummy variable for each brand in several of the periods. Accordingly, the following columns 4 and 8 show regressions

CHART III.1

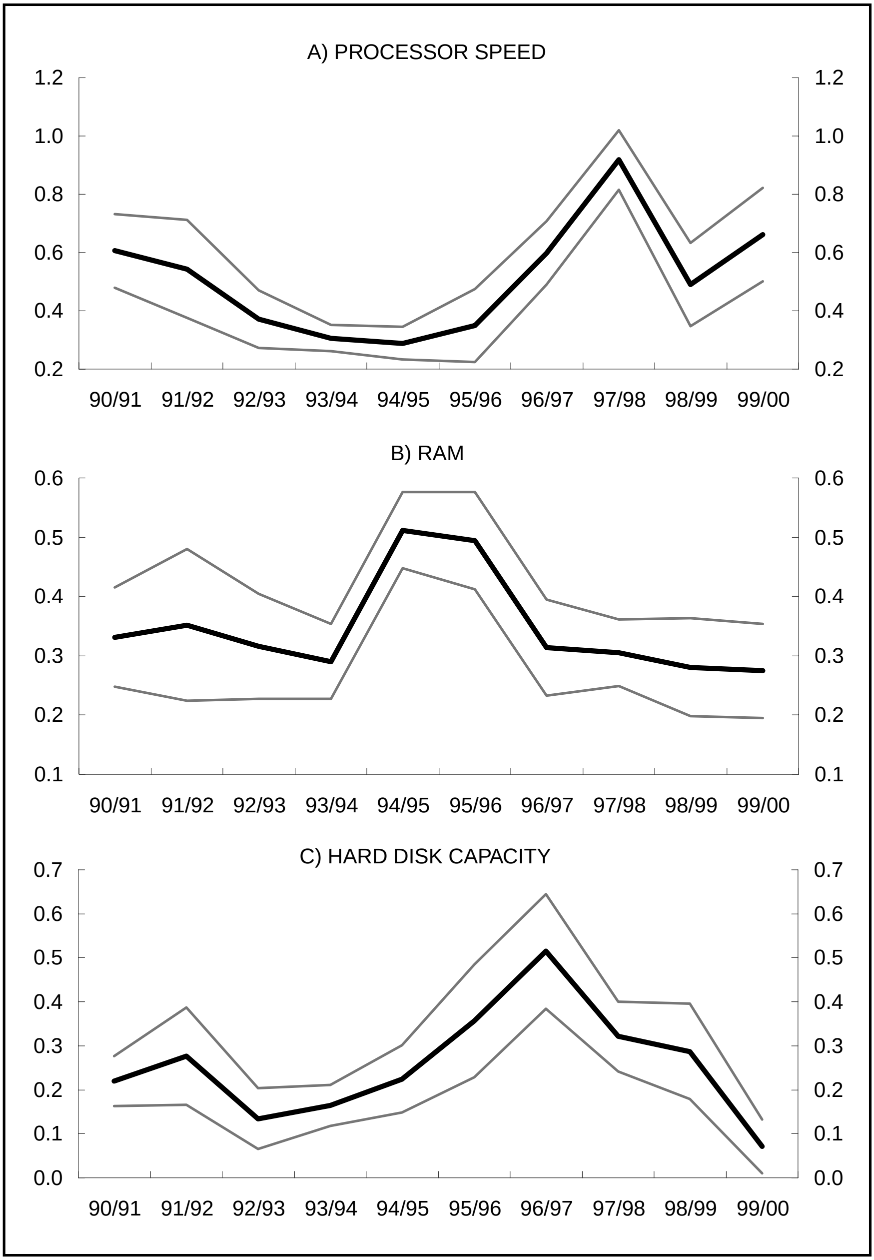
ESTIMATED COEFFICIENTS OF DESKTOP COMPUTER CHARACTERISTICS. SEMI-LOGARITHMIC SPECIFICATION WITH BRAND DUMMY VARIABLES WITH ADJACENT REGRESSIONS



Source: Banco de España.

CHART III.2

ESTIMATED COEFFICIENTS OF DESKTOP COMPUTER CHARACTERISTICS. DOUBLE LOGARITHMIC SPECIFICATION, WITH BRAND DUMMY VARIABLES WITH ADJACENT REGRESSIONS



Source: Banco de España.

TABLE III.3

HEDONIC REGRESSIONS FOR DESKTOP COMPUTERS BASED ON ADJACENT PERIODS

	Average values in the ten regressions							
Specification	Semi-logarithmic				Double logarithmic			
	1	2	3	4	5	6	7	8
Brand variables	Yes	No	No	Cloned	Yes	No	No	Cloned
p-value brand	0.00	—	—	0.00	0.00	—	—	0.00
Sample	All	All	Cloned	All	All	All	Cloned	All
Observations	264	264	217	264	264	264	217	264
Adjusted R^2	0.81	0.52	0.56	0.57	0.85	0.54	0.57	0.60

Source: Banco de España.

for the total sample including a single dummy variable encompassing all the computers identified as cloned. The statistics in this table correspond to the average of the ten regressions made, one for each pair of periods, between 1990-1991 and 1999-2000. The adjusted R^2 of both specifications hover around 80 % when brand dummy variables are included for the entire sample, while they are above 50 % when the dummies are eliminated and the complete sample is maintained or the estimation is made solely for the cloned computers. The inclusion of a dummy variable encompassing all the cloned computers in the total sample only slightly increases the explanatory power of the regression. The differences previously observed between the semi-logarithmic and double logarithmic specifications have been reduced, although the latter continues to offer a slightly better fit. As to the estimation of the coefficients of the characteristics, see Charts III.1 and III.2 for a sample where both specifications show the expected positive signs in all cases, with each of the estimated coefficients being, moreover, significant.

In principle, therefore, the first of the estimations could be selected for either of the two specifications, since they provide the best fits. However, the estimation of the brand dummy variable in these regressions for adjacent years poses problems related to the estimation of the time dummy variable. Specifically, in the estimation for the years 1993 and 1994, only a brand with observations present in those periods is available. Therefore, estimating a dummy variable for each of the brands present in the two years along with a time dummy variable brings about a situation which the brand dummy variables present in a single period reflect a large part of the effect attributable to the time dummy variable. For this reason, in the estimations made for adjacent years it is preferred to resort to the estimation of the time dummy variables of the regressions without

TABLE III.4

PERIOD-BY-PERIOD HEDONIC REGRESSIONS FOR DESKTOP COMPUTERS

Average values in the eleven regressions						
Specification	Semi-logarithmic			Double logarithmic		
	1	2	3	4	5	6
Brand variable	No	Cloned	No	No	Cloned	No
p-value brand	—	0.00	—	—	0.00	—
Sample	All	All	Cloned	All	All	Cloned
Observations	132	132	110	132	132	110
Adjusted R^2	0.52	0.58	0.56	0.53	0.60	0.55

Source: Banco de España.

brand dummy variables. In particular, the estimation for the entire sample, where a single dummy variable is included for all the cloned computers, proves to be that which offers a better fit in the two specifications, with the fit achieved in the double logarithmic specification being superior. In turn, a greater cumulative fall in prices between 1990 and 2000 is obtained under this specification.

A second method for allowing time variation in the implicit prices of the characteristics is to make a period-to-period estimation of the hedonic function. In this latter case, the estimation of (quality-adjusted) inflation in computers will be made constructing what is known as a characteristics price index, which involves no more than constructing a given-characteristics price index, i.e. evaluating the annual changes in the prices of the characteristics (estimated in the annual hedonic regressions) in a characteristic vector of the base period. It is therefore necessary to have an estimation of the prices of each of the characteristics included in the regression to construct the index. Since the different brands enter and leave the sample, their price cannot be calculated in each of the years. Therefore, the estimations made do not include the brand dummy variables among the regressors. Table III.4 summarises the basic statistics of the regressions made. The first three columns showed the results obtained under the semi-logarithmic specification, while the following three columns refer to the double logarithmic specification. In each case, the first two columns show the results for the total sample, including a cloned dummy variable in the second two columns, while columns 3 and 6 offer the results for a sample of cloned computers. It can be seen how the results are similar to the regressions made for adjacent periods, although the adjusted R^2 is somewhat lower, oscillating between 50 % and 60 %, obtaining very similar adjustments under the two specifications and always being slightly higher when the entire sample is used and a dummy variable is included to identify the cloned computers. Problems in estimating the hedonic function arise in certain years and, relatively frequently, some of the variables included in the regression do not prove significant.

In short, estimations of the hedonic function have been made under two alternative specifications (semi-logarithmic and double logarithmic) for the complete data pool, for adjacent-year periods and on a period-to-period basis. The results denote a better fit of the regressions under the double logarithmic specification and the need to abandon the assumption that the prices of the characteristics present in the regressions for the complete data pool are constant. The regressions for adjacent periods and on a period-to-period basis yield similar results, although several problems appear in the latter in estimating the prices of characteristics for certain years that make adjacent-period estimation preferable. Consequently, the hedonic price indices constructed in Chapter IV are those obtained with adjacent-period estimations.

III.2. Laptop computers

As regards laptop computers, Tables III.5 and III.6 offer the results of the estimation of [I.1] with the entire data pool and with the semi-logarithmic and double logarithmic functional forms, respectively. The first column of these tables gives the estimation in which a dummy variable is included for each of the brands present in the sample (in total there are 141). In the second column, and in order to reduce the number of explanatory variables, the dummy variables have been replaced by a single dummy that takes the value of 1, when the computer is cloned, and zero otherwise. In the third column, and so it may act as a point of reference, the estimation is included without any of these dummy variables, so that on comparing it with the previous estimations, it can be seen whether the brand influences the price of the computer.

As can be seen in these tables, the best fits are obtained with the double logarithmic specification (with an adjusted R^2 between 52 % and 69 %) and the worst ones with the semi-logarithmic specification (between 36 % and 53 %). Further, and irrespective of the functional form, the significance of the brand is highlighted as another of the characteristics which determine computer prices. Consequently, the hypothesis is accepted that there are further aspects, other than the characteristics taken into account, which allow manufacturers price differentiation and, therefore, it is preferable to use regressions that include brand dummy variables. The implicit prices of the characteristics show the expected signs. The time dummy variables, for their part, exhibit a diminishing profile of the prices adjusted for changes in the sample’s characteristics; with

TABLE III.5

HEDONIC REGRESSIONS FOR LAPTOP COMPUTERS WITH SEMI-LOGARITHMIC SPECIFICATION. JOINT ESTIMATION FOR THE PERIOD 1990-2000

	1	2	3	4	5	6
Speed	0.0031	0.0026	0.0024	0.0055	0.0043	0.0042
	(7.16)	(5.72)	(5.19)	(7.67)	(6.05)	(5.80)
RAM	0.0064	0.0037	0.0033	0.0058	0.0019	0.0013
	(4.61)	(2.78)	(2.40)	(3.07)	(1.03)	(0.71)
Hard disk	0.00004	0.00006	0.00007	0.00003	0.00004	0.00005
	(2.76)	(4.18)	(5.00)	(1.58)	(2.05)	(2.42)
Weight	—	—	—	0.0715	0.0412	0.0415
				(4.36)	(2.39)	(2.37)
d-1991	-0.3157	-0.2157	-0.2303	-0.0606	-0.0812	-0.0930
	-(4.67)	-(3.70)	-(3.86)	-(0.68)	-(0.95)	-(1.08)
d-1992	-0.7199	-0.7606	-0.8016	-0.5145	-0.6074	-0.6515
	-(7.29)	-(11.24)	-(11.63)	-(4.22)	-(6.30)	-(6.69)
d-1993	-0.7186	-0.6413	-0.6702	-0.4629	-0.5148	-0.5392
	-(10.38)	-(11.30)	-(11.57)	-(5.03)	-(5.96)	-(6.16)
d-1994	-0.2498	-0.2507	-0.2391	0.0098	-0.1181	-0.1065
	-(3.12)	-(3.73)	-(3.47)	(0.10)	-(1.22)	-(1.09)
d-1995	-0.3552	-0.3827	-0.3312	-0.1840	-0.3085	-0.2628
	-(4.52)	-(5.83)	-(4.97)	-(1.72)	-(3.11)	-(2.62)
d-1996	-0.6864	-0.6319	-0.6099	-0.5772	-0.6112	-0.5737
	-(6.87)	-(8.56)	-(8.08)	-(3.79)	-(4.73)	-(4.38)
d-1997	-0.8856	-0.8400	-0.8003	-0.7770	-0.6527	-0.5831
	-(10.01)	-(10.56)	-(9.86)	-(4.69)	-(4.27)	-(3.78)
d-1998	-0.9091	-0.8055	-0.7889	-0.9516	-0.8199	-0.8017
	-(9.15)	-(8.66)	-(8.29)	-(6.36)	-(5.74)	-(5.53)
d-1999	-1.2990	-1.0822	-1.0230	-1.5874	-1.1838	-1.1091
	-(11.28)	-(10.52)	-(9.76)	-(8.58)	-(7.33)	-(6.80)
d-2000	-2.3579	-2.0729	-2.0155	-2.8407	-2.4216	-2.3516
	-(13.04)	-(11.67)	-(11.10)	-(9.41)	-(8.33)	-(7.98)
Constant	13.1507	13.2156	13.1400	12.6576	12.9204	12.8512
	(247.51)	(285.95)	(288.51)	(107.27)	(106.96)	(105.68)
Cloned	—	-0.1673	—	—	-0.1473	—
		-(6.02)			-(4.28)	
p-value brand	0.00	—	—	0.00	—	—
Sample	All	All	All	With weight	With weight	With weight
Observations	740	740	740	560	560	560
Adjusted R^2	0.5317	0.4044	0.3634	0.5673	0.4024	0.3834
F(n, m)	26.62	35.16	33.45	22.39	26.1	25.83
	(13, 585)	(14, 725)	(13, 726)	(14, 421)	(15, 544)	(14, 545)

Source: Banco de España.

TABLE III.6

HEDONIC REGRESSIONS FOR LAPTOP COMPUTERS WITH DOUBLE LOGARITHMIC SPECIFICATION. JOINT ESTIMATION FOR THE PERIOD 1990-2000

	1	2	3	4	5	6
Speed	0.3986	0.2926	0.2373	0.3803	0.2830	0.2439
	(7.07)	(4.99)	(3.97)	(6.17)	(4.36)	(3.70)
RAM	0.2399	0.1654	0.1702	0.3046	0.1944	0.1995
	(7.14)	(5.07)	(5.07)	(7.67)	(4.92)	(4.95)
Hard disk	0.30252	0.32896	0.35994	0.23817	0.29772	0.31447
	(9.09)	(9.41)	(10.10)	(6.30)	(7.46)	(7.75)
Weight	—	—	—	0.1760	0.0583	0.0390
				(3.01)	(0.91)	(0.60)
d-1991	-0.5009	-0.3869	-0.3932	-0.3677	-0.3443	-0.3650
	-(8.95)	-(7.42)	-(7.33)	-(5.13)	-(4.79)	-(4.98)
d-1992	-1.0293	-1.1779	-1.2103	-0.8732	-1.0957	-1.1470
	-(12.61)	-(18.59)	-(18.63)	-(8.74)	-(12.53)	-(12.94)
d-1993	-1.3775	-1.3331	-1.3616	-1.2158	-1.2800	-1.3177
	-(21.75)	-(21.89)	-(21.80)	-(14.72)	-(14.91)	-(15.09)
d-1994	-1.3456	-1.2758	-1.2809	-1.1246	-1.2027	-1.2138
	-(16.58)	-(16.36)	-(15.97)	-(10.77)	-(11.44)	-(11.31)
d-1995	-1.9832	-1.8558	-1.8139	-1.7192	-1.7574	-1.7238
	-(19.59)	-(18.69)	-(17.80)	-(13.40)	-(13.65)	-(13.13)
d-1996	-2.6304	-2.3713	-2.3592	-2.2982	-2.2719	-2.2452
	-(20.68)	-(20.19)	-(19.53)	-(13.61)	-(14.30)	-(13.85)
d-1997	-3.0173	-2.7811	-2.7548	-2.6059	-2.4862	-2.4290
	-(22.94)	-(21.09)	-(20.32)	-(14.08)	-(13.48)	-(12.92)
d-1998	-3.2031	-2.8978	-2.9023	-2.8903	-2.7239	-2.7233
	-(21.90)	-(19.53)	-(19.01)	-(16.09)	-(14.98)	-(14.67)
d-1999	-3.6045	-3.1686	-3.1305	-3.3388	-3.0135	-2.9545
	-(22.72)	-(20.21)	-(19.43)	-(17.40)	-(15.83)	-(15.23)
d-2000	-4.3008	-3.8198	-3.7817	-3.8731	-3.6373	-3.5856
	-(23.79)	-(20.75)	-(19.99)	-(16.72)	-(15.35)	-(14.83)
Constant	11.1197	11.4252	11.3870	11.0573	11.4420	11.4508
	(73.45)	(76.94)	(74.61)	(58.68)	(59.52)	(58.34)
Cloned	—	-0.1588	—	—	-0.1462	—
		-(6.57)			-(4.92)	
p-value brand	0.00	—	—	0.00	—	—
Sample	All	All	All	With weight	With weight	With weight
Observations	740	740	740	560	560	560
Adjusted R^2	0.6901	0.5427	0.5161	0.7167	0.5589	0.5401
F(n, m)	63.25	63.64	61.36	50.06	48.23	47.90
	(13, 585)	(14, 725)	(13, 726)	(14, 421)	(15, 544)	(14, 545)

Source: Banco de España.

the double logarithmic functional form there is a break only in 1994, while with the semi-logarithmic specification this circumstance recurs both in 1994 and in 1993. As to cumulative quality-adjusted inflation over the whole of the sample period (obtained from the coefficient estimated for the dummy variable corresponding to 2000), this varies according to the specification, with the biggest decline being obtained with the double logarithmic functional form with brand variables.

As one of the characteristics of laptop computers valued by purchasers is weight, the previous estimations have been replicated, but restricting the sample to the computers whose weight is known and including weight as an additional characteristic. And this despite the fact that the already smaller sample is cut by almost 25 %. Columns 4 to 6 of Tables III.5 and III.6 show the results of these estimations. According to these findings, the weight variable is not always significantly different from zero; but when it is, it appears with a positive sign, which in principle seems counter-intuitive. This result may be due to the fact that in reality it is acting as a proxy variable of another (other) unobserved characteristic(s) included in the computer which make(s) its weight increase. In this respect, it should be borne in mind that although technological innovation is pivotal when explaining the reduction that has taken place in the weight of laptop computers (from 13 kilograms at the outset to 1.4 kilograms in some computers nowadays), this fall has also come about due to certain computer accessories, such as the battery (4), the CD or DVD reader and the disk drive, being made external. Consequently, it might be the case that the heavier the computer the better its performance. Unfortunately, there is no information on this matter in the database. Therefore, it is not possible to test the validity of this hypothesis. Were it true that accessories differ from computer to computer, they should be included in the regressions as additional characteristics. Moreover, in the semi-logarithmic specification, when weight is included, hard disk capacity or RAM and some of the time dummy variables (essentially those relating to 1991,1994 and 1995) cease to be significant.

The use of a proxy in the hedonic regression may be problematic since, as indicated in Triplett (2000), its relationship to the variable it is attempting to proxy may alter over time, thereby detracting from the validity of the estimation. Accordingly, and owing to the lack of significance of some of the remaining variables when weight is taken into account, if one of the estimations with the data pool had to be selected, it would seem sensible to choose the regression with the double logarithmic functional form with brand variables and without weight. It should be mentioned that, with laptop computers, the type of processor has not come to be included as an ex-

(4) The characteristic most closely related to weight is probably the computer battery.

TABLE III.7

HEDONIC REGRESSIONS FOR LAPTOP COMPUTERS BASED ON ADJACENT PERIODS

Specification	Average values in the ten regressions					
	Semi-logarithmic			Double logarithmic		
	1	2	3	4	5	6
Brand variables	Yes	No	No	Yes	No	No
Cloned variable	No	Yes	No	No	Yes	No
p-value brand	0.00	—	—	0.00	—	—
Sample	All	All	All	All	All	All
Observations	134	134	134	134	134	134
Adjusted R^2	0.67	0.45	0.42	0.71	0.47	0.44

Source: Banco de España.

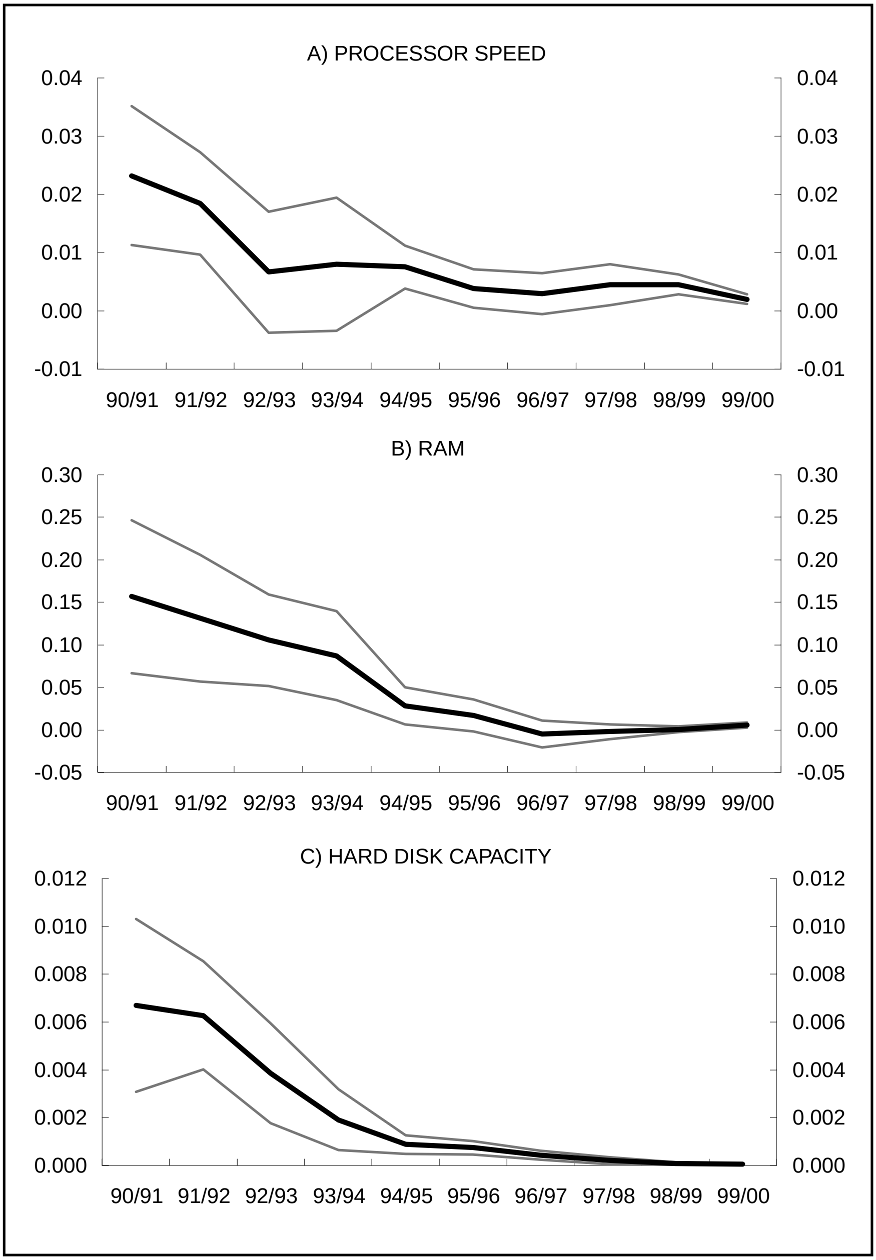
planatory variable as it was with desktop computers. This is because this information is only available for a very limited number of computers; indeed, in certain years this characteristic is unknown in all computers.

As earlier mentioned, and for the same reasons as those brandished for desktop computers, the estimations of the data pool are restrictive and should only be taken as a starting point, i.e. an attempt should be made to exceed the results with other specifications. It seems more advisable to estimate using adjacent periods. The average of the basic statistics of the ten estimations made in this way is provided, for the different specifications, in Table III.7. The estimations with the weight variable have not been included because the same problems as discussed on presenting the pool estimations arise, exacerbated by the fact that in certain years the sample diminishes most significantly.

Once again, the fit improves substantially when the computer brand is taken into account, whereas there are no major differences between including a dummy variable for all the cloned computers or not controlling at all for the brand. With both functional forms, the fits improve notably compared with the data pool estimation, with the double logarithm providing the highest adjusted R^2 (71 % on average, when brand variables are included). To illustrate whether it is appropriate or not to allow the β_j coefficients to vary over time, Charts III.3 and III.4 depict the estimated coefficients of the characteristics considered, with their confidence intervals at 95 %, for the estimations made with brand variables, whether with the semi-logarithmic or with the double logarithmic specification. Both charts confirm that is not appropriate to impose the constancy of the coefficients of the characteristics throughout the entire pe-

CHART III.3

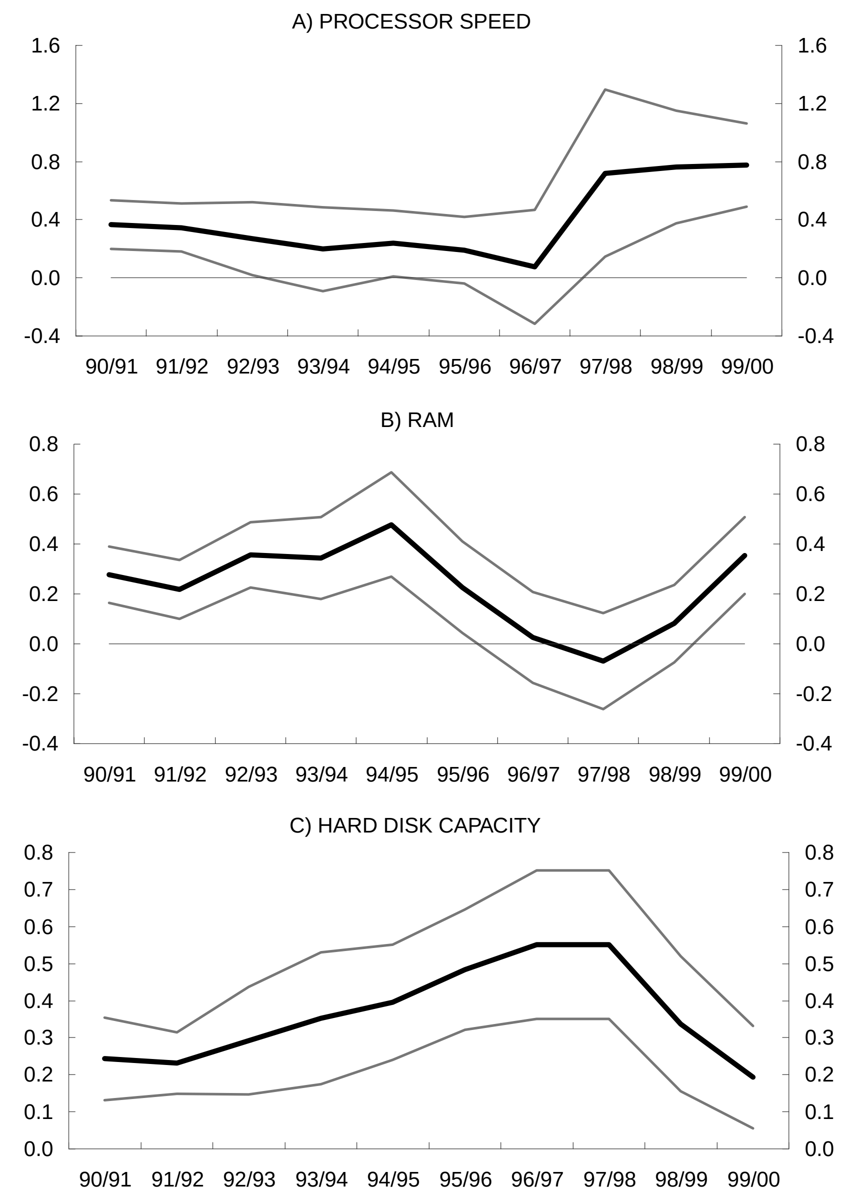
ESTIMATED COEFFICIENTS OF LAPTOP COMPUTER CHARACTERISTICS. SEMI-LOGARITHMIC SPECIFICATION WITH BRAND DUMMY VARIABLES WITH ADJACENT REGRESSIONS



Source: Banco de España.

CHART III.4

ESTIMATED COEFFICIENTS OF LAPTOP COMPUTER CHARACTERISTICS. DOUBLE LOGARITHMIC SPECIFICATION WITH BRAND DUMMY VARIABLES WITH ADJACENT REGRESSIONS



Source: Banco de España.

TABLE III.8

PERIOD-BY-PERIOD HEDONIC REGRESSIONS FOR LAPTOP COMPUTERS

Average values in the eleven regressions						
Specification	Semi-logarithmic			Double logarithmic		
	1	2	3	4	5	6
Brand variables	Yes	No	No	Yes	No	No
Cloned variable	No	Yes	No	No	Yes	No
p-value brand	0.02	—	—	0.03	—	—
Sample	All	All	All	All	All	All
Observations	67	67	67	67	67	67
Adjusted R^2	0.64	0.42	0.38	0.66	0.43	0.38

Source: Banco de España.

riod (5). Likewise, with Chow tests, the stability of the parameters is rejected. It might however be acceptable for some of the sub-periods, in one of the estimated specifications, to be extended to three years. Even so, the study only offers estimations with adjacent periods of two by two years, since the results are very similar (6). Unfortunately, at very specific times, it cannot be rejected that processor speed or the amount of RAM may not be significantly different from zero, at a 95 % confidence level; this result might be due to the presence of multicollinearity. Were this true, the accuracy of the estimation would diminish, with the subsequent danger of eliminating relevant variables. This, along with the fact that, as indicated in section I.1, multicollinearity need not invalidate the resulting hedonic price indices, has led these two characteristics to be maintained in all the estimations of hedonic relations. As occurs with desktop computers, with the semi-logarithmic specification the implicit prices of characteristics show a diminishing profile, while with the double logarithmic specification the behaviour of the coefficients is much less clear.

Lastly, period-by-period hedonic regressions have been estimated. The average values of the basic statistics obtained with the eleven regressions are provided in Table III.8. Broadly, the results are similar

(5) This result is common to all the estimations in Table III.7. However, not all the $\hat{\beta}_j$ have been depicted so as not to incur in excessive graphics.

(6) For example, although in the estimation with the double logarithmic functional form and brand variables the stability of parameters in the sub-periods 1990-1992, 1992-1994 and 1997-1999 cannot be ruled out, even the annual average rates of change (which are calculated later) for the periods 1990-2000 and 1992-2000 are of the same order of magnitude whether a length of three years for these sub-periods is imposed or not.

to those obtained with the other two forms of estimation. That is to say, the best fit (66 % on average) is achieved with the double logarithmic specification and with brand variables. Nonetheless, the regressions in which at least one of the coefficients of the characteristics is not significantly different from zero cease to be discrete, becoming generalised. This, along with the lesser adjustment in respect of the adjacent-period estimation, leads period-by-period estimations to be ruled out.

In sum, based on the conjunction both of the problems detected in the various regressions made and the objective of maximising the explanatory power of the independent variables, the double logarithmic specification with brand dummy variables estimated by adjacent periods appears to be the most appropriate one for describing changes in the price of laptop computers.

IV

HEDONIC PRICE INDICES

Having ruled out first, imposing that the prices of the characteristics hold constant and, second, period-by-period estimations, owing to the problems they pose in the estimation of the prices of characteristics for certain years, it is adjacent-period estimations that will be used to construct hedonic price indices (1). So that these indices may measure computer prices adjusted for quality changes during the period under study, they are constructed – as detailed in section I.2 – directly from the estimation of the time dummy variables.

As Triplett (2000) affirms, the price indices should not be chosen mechanically maximising the R^2. It is also important to examine the plausibility of the indices obtained with a different type of information. Therefore, despite the apparent superiority shown by the estimations with the double logarithmic form, it is considered worthwhile to calculate the hedonic price indices that are obtained using the various adjacent-period estimations in Chapter III. In this way, the behaviour of all of them can be analysed and compared.

IV.1. Desktop computers

Table IV.1 shows the average rates of change of the price indices constructed from the various adjacent-period estimations made for the complete period between 1990 and 2000, as well as for the sub-periods 1990-1995 and 1995-2000. The first four columns show the average behaviour of the indices constructed from the semi-logarithmic specification, while

(1) Nonetheless, hedonic price indices have been constructed for each of the regressions in the previous chapter. Tables A.3 and A.4 in the Appendix show the average behaviour of the indices calculated on the basis of the regressions for the data pool and the period-by-period regressions.

TABLE IV.1

HEDONIC PRICE INDICES FOR DESKTOP COMPUTERS BASED ON ADJACENT-PERIOD ESTIMATIONS. ANNUAL AVERAGE CHANGE IN THE PERIOD 1990-2000

	Semi-logarithmic				Double logarithmic			
Brand variables	Yes	No	No	Cloned	Yes	No	No	Cloned
Sample	All	All	Cloned	All	All	All	Cloned	All
ANNUAL AVERAGE CHANGE:								
2000-1990	-32.18	-35.83	-38.45	-35.00	-36.77	-40.82	-41.82	-40.06
1995-1990	-20.58	-32.15	-34.03	-33.84	-24.19	-36.14	-37.69	-37.75
2000-1995	-42.08	-39.31	-42.57	-36.13	-47.26	-45.15	-45.69	-42.29

Source: Banco de España.

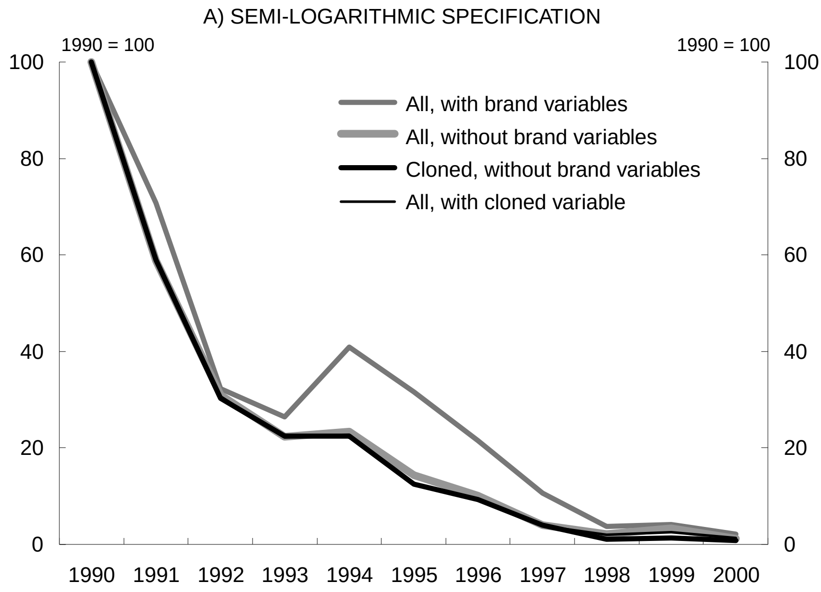
the following four columns showed those relating to the double logarithmic specification, whose estimations were presented in Table III.3. As can be seen, the average price falls during the period are most significant. Chart IV.1 exhibits the various indices calculated. These show, for both specifications, annual average price falls of between 32 % and 42 % (2) for the period 1990-2000, with somewhat greater declines being estimated under the double logarithmic specification, while the lowest falls are obtained with brand dummy variables in the regressions for the full sample.

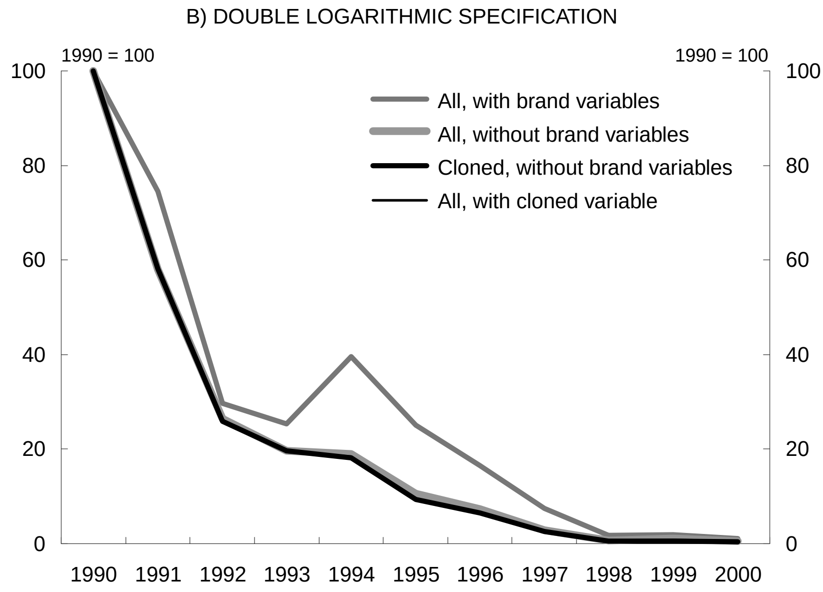
The latter result is motivated by the strange behaviour in 1994 of the price index constructed for the full sample when brand dummy variables are included in the specification. In that year, a most significant price increase is estimated (see Chart IV.1), which appears to bear no relation to the average behaviour of prices or to the increase in the characteristics of the average computer that year (see Chart II.1). The joint estimation of the time dummy variable for this year along with the brand dummy variables appears to be responsible for this behaviour. It was earlier mentioned that the distribution of the brand dummy variables is very uneven in the sample. This means that between the years 1993 and 1994 there was just one brand present in both periods. Therefore, much of the behaviour of the time dummy variable is reflected in the brand dummy vari-

(2) Table A.3 in the Appendix shows the average growth rates of the price indices calculated on the basis of the estimations for the pool data and the period-by-period estimations. The average rates of decline of prices can be seen to be similar to those presented for adjacent periods, if the semi-logarithmic estimation for the full data pool is ruled out. This specification, along with the assumption of shadow prices of the characteristics holding constant, appears to shape an overly restrictive approach that offers a worse data fit and lower average falls in the price indices.

CHART IV.1

HEDONIC PRICE INDICES FOR DESKTOP COMPUTERS ON THE BASIS OF REGRESSIONS FOR ADJACENT PERIODS





Source: Banco de España.

ables, which are present in just one of the two adjacent periods. Consequently, estimation without brand dummy variables is considered more appropriate since, although less explanatory power is had, this allows a more robust estimation of the time dummy variables and, therefore, of the quality-adjusted price index. In the remaining estimations, the price increases in 1994 are virtually nil and the average decline over the period stands in a narrower range of between 35 % and 42 %. More specifically, the price indices show a fall of between 40 % and 42 %, under the double logarithmic specification, which falls to 35-38 % under a semi-logarithmic specification. Chart IV.1 shows how the trend of the various indices during the years prior to and after 1994 is very similar. The same chart reveals how the price falls are more sizeable between 1990 and 1992, moderating in the following two years to then accelerate between 1995 and 1998, while in 1999 a considerable price increase takes place (3). Overall, this translates into a notable acceleration in the rate of decline of prices in the second half of the nineties, as reflected in the rates shown in Table IV.1.

When selecting an index from among those calculated, the double logarithmic specification, estimated for adjacent periods including a dummy variable for cloned computers in the full sample, is seen to be the best choice. Chart IV.2 depicts the annual rates of change of this price index, which shows an average rate of decline between 1990 and 2000 of 40 % per year. This result is similar to that obtained in Berndt and Rappaport (2001), who estimate an average fall of 39 % for personal computers in the United States between 1994 and 1998, and is in the upper part of the range of price falls estimated for this country by other studies. For example, Aizcorbe et al. (2000) estimate a decline of 31 % for desktop computers over the same period, while the price index of the US Bureau of Economic Analysis for personal computers falls to 32 % per year in these years.

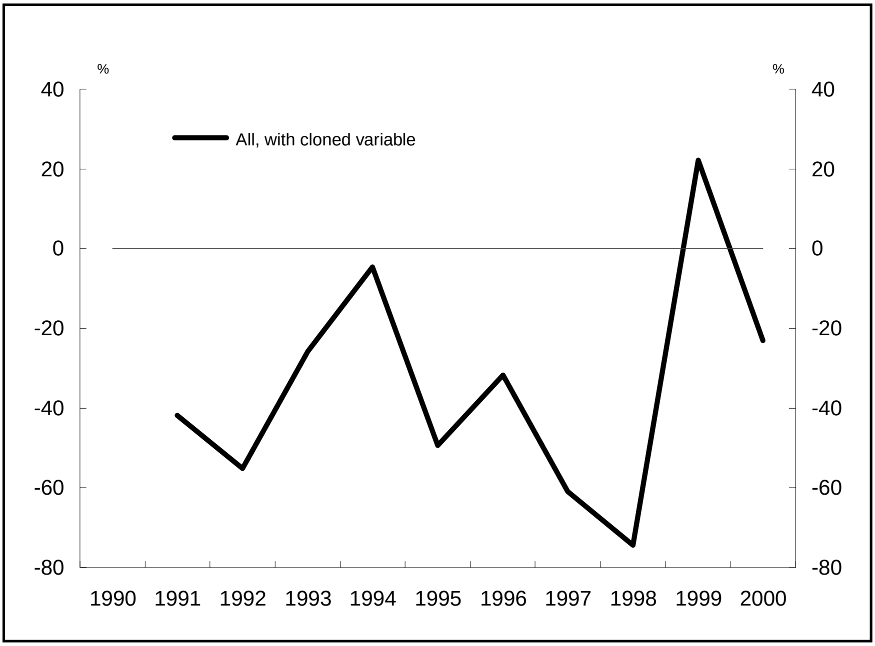
IV.2. Laptop computers

Table IV.2 gives the annual average rates of change in the period 1990-2000, as well as for the sub-periods 1995-1990 and 2000-1995, which are obtained for the various hedonic price indices constructed for laptop computers on the basis of the adjacent-period estimations in Table III.7. Moreover, Chart IV.3.A depicts the indices corresponding to the estimations with the semi-logarithmic functional form, while Chart IV.3.B of-

(3) This price increase may be related to the worldwide shortage of RAM components following the September 1999 earthquakes in Taiwan. Moreover, the increase in the demand for computers brought on by the arrival of the year 2000 may also have been influential.

CHART IV.2

HEDONIC PRICE INDICES FOR DESKTOP COMPUTERS BASED ON REGRESSIONS FOR ADJACENT PERIODS (a)



Source:Banco de España.
(a) Year-on-year rate of change.

fers the equivalent indices, but with the double logarithmic functional form. As can be seen in Table IV.2, the interval in which the annual average rates of decline of these indices for the period 1990-2000 move ranges from 31 % to 36 % (4). In respect of specifications, the smallest declines are with the semi-logarithmic one. Irrespective of the functional form, the reductions increase as the brand is progressively controlled for. That is to say, if a dummy variable is included to identify whether the computer is cloned or not, the annual average change is greater than when it is not included, and it increases once more on replacing the dummy variable with independent variables for each brand. That said, as can be seen in Chart IV.3, the profiles obtained when the brand is not at all controlled for are similar to those resulting from using a dummy variable

(4) Table A.4 in the Appendix shows the average growth rates of the price indices in the period 1990-2000 calculated on the basis of the estimations for the pool data and the period-by-period estimations. As can be seen, with both forms of estimation and under the double logarithmic specification the price falls are very similar to those obtained with the adjacent-period estimations. However, the price reductions are rather more moderate if the semi-logarithmic specification is involved and estimation is not by adjacent periods.

TABLE IV.2

HEDONIC PRICE INDICES FOR LAPTOP COMPUTERS BASED ON ADJACENT-PERIOD ESTIMATIONS ANNUAL AVERAGE CHANGE IN THE PERIOD 1990-2000

	Semi-logarithmic			Double logarithmic		
Brand variables	Yes	No	No	Yes	No	No
Cloned variable	No	Yes	No	No	Yes	No
ANNUAL AVERAGE CHANGE:						
2000-1990	-32.71	-31.46	-30.84	-35.73	-32.73	-32.00
1995-1990	-26.77	-27.20	-26.75	-32.21	-30.52	-29.87
2000-1995	-38.17	-35.47	-34.69	-39.06	-34.87	-34.07

Source: Banco de España.

that groups all cloned computers. Moreover, irrespective of the specification, the indices posted notable reductions in 1991 and 1992, while in 1994 an increase in the price of laptop computers not attributable to the changes in the characteristics considered was observed (5). Since 1995, the indices have returned to a declining path, showing significant cuts. Indeed, evident in all cases is a stepping up of price reductions in the second half of the decade compared with the first half (see the last two lines of Table IV.2).

Bearing in mind that the best fits of the various estimations considered for the calculation of the indices are obtained with brand variables, the prices adjusted for the characteristics of processor speed, amount of RAM and hard disk capacity may be said to have declined on average by 33-36 % between 1990 and 2000, depending on whether it was a semi-logarithmic or double logarithmic functional form. These figures are somewhat lower than those attained for desktop computers. However, it should be noted that for the latter it was possible to control for additional characteristics. As to their annual trend, Chart IV.4 depicts the year-on-year rate of change of the indices selected. As can be seen, in all the years analysed -with the exception of 1994- these indices posted heavy falls, particularly so in the years 1991-1993, 1995-1996 and 1999-2000. Although the results are very similar with both indices, the double logarithmic specification has been chosen to construct the hedonic index for personal computers, as it is that which provides the best fit.

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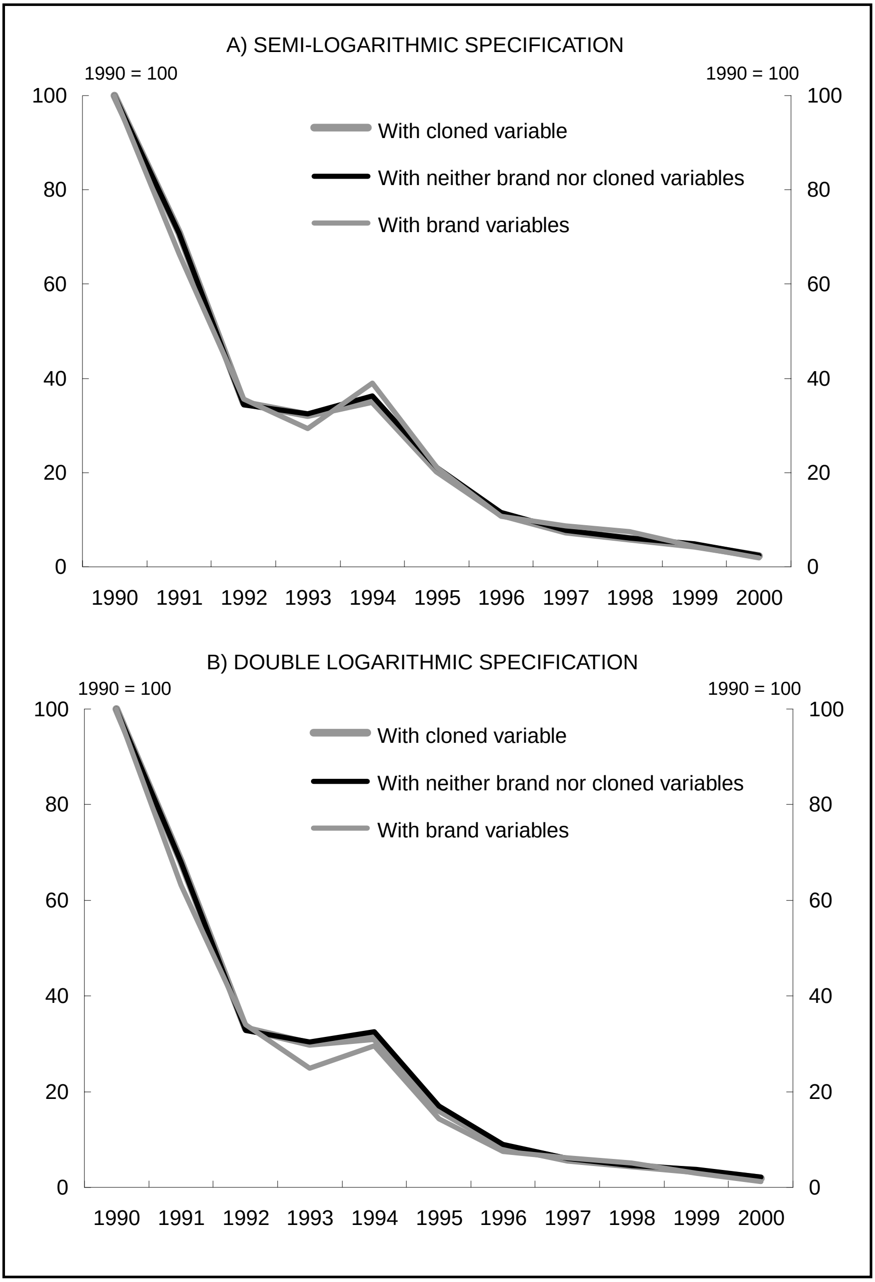
(5) One explanation for this behaviour may be related to the notable increase in the demand for laptop computers, approximately as from this year, given that the successive reductions in their weight meant that such computers evolved from that year onwards from being merely transportable to becoming true laptops.

CHART IV.3

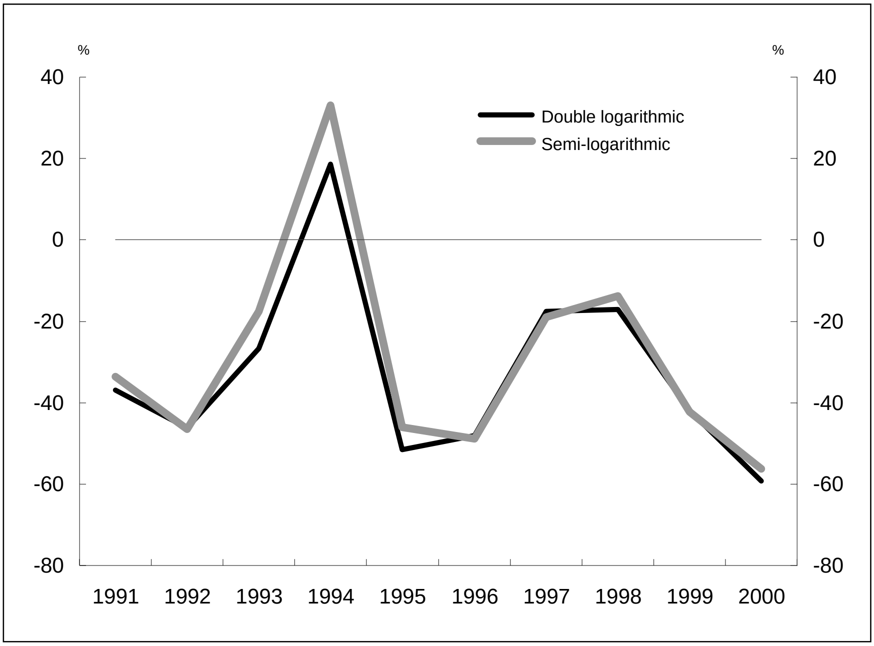
HEDONIC PRICE INDICES FOR LAPTOP COMPUTERS BASED ON REGRESSIONS FOR ADJACENT PERIODS



Source: Banco de España.

CHART IV.4

HEDONIC PRICE INDICES FOR LAPTOP COMPUTERS BASED ON REGRESSIONS FOR ADJACENT PERIODS WITH BRAND VARIABLES (a)



Source: Banco de España.

(a) Year-on-year rate of change.

To conclude, these results are in line with those of Berndt and Rappaport (2001) for the United States. In their study they find that the falls in quality-adjusted prices have been greater in desktop than in laptop computers. For laptops they estimate a far greater fall in the annual average growth rate in the period 1994-1999 (around 42 %) than during 1989-1994 (20 %). In this study, a somewhat more moderate annual average rate of change is obtained for the period 1994-1999 (-37 %), although the rate of change of these prices has also intensified in recent years. Thus, the annual average growth rate recorded during the period 1990-1994 was -26 %. However, the results are rather more moderate than those obtained by Aizcorbe et al. for US laptop computers in the period 1995-1999 (-66 %).

IV.3. Quality bias: hedonic price indices and the CPI

The separately calculated hedonic price indices for desktop and laptop computers in the foregoing sections should be aggregated to form a

TABLE IV.3

HEDONIC PRICE INDICES FOR COMPUTERS

Year	Desktop computers	Laptop computers	Both (simple average)
1990	100.00	100.00	100.00
1991	58.14	63.16	60.65
1992	26.09	34.00	30.04
1993	19.36	24.91	22.14
1994	18.48	29.55	24.01
1995	9.35	14.32	11.83
1996	6.39	7.44	6.92
1997	2.49	6.13	4.31
1998	0.64	5.08	2.86
1999	0.78	2.95	1.87
2000	0.60	1.20	0.90
ANNUAL AVERAGE CHANGE:			
1990-2000	-40.06	-35.73	-37.56
1990-1995	-37.75	-32.21	-34.75
1995-2000	-42.29	-39.06	-40.26

Source: Banco de España.

single hedonic price index for personal computers. Comparing this index with the official price series yields a quantification of the quality bias present in the Spanish case due to insufficient adjustment of prices in the face of the enormous quality changes that have taken place in computers.

As mentioned in the previous sections, from among the various hedonic price indices estimated both for desktop and laptop computers, it is preferable to use the indices calculated under the double logarithmic specification for adjacent periods. There, the entire sample available is used and a dummy variable identifying the cloned computers in the case of desktop computers, and a dummy variable for each of the brands, in the case of laptop computers, are introduced. These two indices are presented in the first two columns of Table IV.3. Sales by type of computer are not available in the database, whereby it is not possible to weight these two indices on the basis of the significance of each type in the market. Nor is there information available on the relative significance of each type of computer in the official series. Accordingly, in order to aggregate the indices, it has been decided to use the simple average. The third column of Table IV.3 shows the aggregate index for computers thus constructed. It posts a fall at an annual average rate of 38 % between 1990 and 2000. The average reductions in prices have been far greater in the second half of the decade (40 %) than in the first (35 %)

As to the official series, the Spanish consumer price index (CPI) for the sub-class of personal computers, typewriters and other includes both the prices of interest to this study and the prices of calculators and typewriters. Nonetheless, the weight of personal computers within this sub-class is predominant, in excess of 90 %. Consequently, it may be assumed that their trend represents that of the official price index for personal computers and, therefore, comparison is possible with the hedonic indices constructed in this study. This sub-class is available as from 1992, meaning comparison with the hedonic price index constructed in this study is confined to 1992-2000. During this period the annual average growth rate of this sub-class was -9 %, while the hedonic index fell at an annual average rate of 35 %. That is to say, the estimation of the quality bias incurred by the Spanish CPI for computers is around 26 % per year.

V

CONCLUSIONS

The hedonic price indices for personal computers in Spain constructed in this study move on a markedly declining course comparable to that of equivalent indices obtained by other researchers for other countries, mainly the United States, and by national statistics offices which already use this methodology. Once the substantial quality changes in the nineties have been stripped out of prices, notable price reductions similar to those in other countries are observable, which was to be expected in the light of the high degree of internationalisation of this sector. The results have been obtained from a sample of personal computers in Spain covering the nineties in their entirety and to which a large part of the database characteristics used for other countries are common.

To obtain these results a wide range of hedonic function specifications has been estimated under different assumptions about the stability of the parameters of this function. It has been found that the estimation of the complete pool of data is too restrictive an approach to reflect the behaviour of the data, while the period-by-period estimation does not allow the shadow prices of all the characteristics considered to be obtained. Accordingly, various hedonic price indices have been calculated on the basis of adjacent-period estimations. With all these indices, price falls that are fairly robust to changes in the specification are obtained, the estimated range for the average fall in prices in the period 1990-2000 being reasonably narrow. The preferred estimation is that for adjacent periods, under a double logarithmic specification; according to this estimation the annual average rate of decline between 1990 and 2000 is 40 % for desktop computer prices, and 36 % for laptop computers. Except for the year 1999 in the case of desktop computers, the time profile of these falls shows an acceleration in the second half of the decade.

However, the analysis performed has several significant limitations. Specifically, it would have been desirable to have full information on the type of processor and, for laptop computers, on the weight, too. Further, the explanatory value of the regressions would have been better if the sample of desktop computers had included more brand manufacturers. Likewise, there is a lack of knowledge about whether the laptop computers have CD-ROM and the accessories included in all computers. Lastly, knowledge of sales would also have been advisable in order to be able to weight the various models according to sales.

As to the estimation of the quality bias present in the computer CPI series, the price falls estimated with the hedonic indices indicate such bias to be most considerable. Indeed, for the period 1992-2000, this bias stands at 26 % per year. When interpreting this figure the above-mentioned limitations of the database available should be recalled; these mean that a degree of caution is necessary as regards the exact scale of the quality bias present in the Spanish CPI. That does not imply, however, that these limitations are necessarily overstating the estimation. In principle, the availability of a more complete database will conceivably tend to discount other technological improvements in computer characteristics that have not been included in this study, which would lead to bigger falls in hedonic price indices.

APPENDIX

TABLE A.1

LIST OF BRANDS IDENTIFIED
AS DESKTOP COMPUTER MANUFACTURERS

AMSTRAD	HYUNDAI
APPLE COMPUTER	IBM
COMPAQ	OLIVETTI
DELL	PACKARD BELL
EPSON IBERICA	SIEMENS NIXDORF
FUJITSU	XEROX
HEWLETT PACKARD	

TABLE A.2

LIST OF BRANDS IDENTIFIED
AS LAPTOP COMPUTER MANUFACTURERS

AMSTRAD	NEC
APPLE	OLIVETTI
COMMODORE	PACKARD BELL
COMPAQ	PANASONIC
DELL	PHILIPS
DIGITAL	SCHNEIDER
ELBE	SHARP
EPSON	SIEMENS
FUJITSU	TEXAS INSTRUMENTS
HEWLETT PACKARD	TOSHIBA
HP	UNISYS
IBM	

TABLE A.3

HEDONIC PRICE INDICES FOR DESKTOP COMPUTERS.
ANNUAL AVERAGE CHANGE IN THE PERIOD 1990-2000

	Semi-logarithmic					Double logarithmic				
JOINT ESTIMATION OF DATA POOL :										
Brand variables	Yes	No	Yes	No	Yes	Yes	No	Yes	No	Yes
Processor type	No	No	No	No	Yes	No	No	No	No	Yes
Sample	All	All	Cloned	Cloned	All	All	All	Cloned	Cloned	All
Annual average change	-20.74	-24.26	-25.66	-26.67	-36.50	-40.38	-37.70	-40.46	-37.82	-33.96
PERIOD-BY-PERIOD ESTIMATION (a):										
Brand variables	No	Cloned	No			No	Cloned	No		
Processor type	No	No	No			No	No	No		
Sample	All	All	Cloned			All	All	Cloned		
Annual average change	-30.66	-32.71	-35.10			-40.08	-42.34	-43.38		

Source: Banco de España.
(a) Based on chained Laspeyres indices of the characteristics.

TABLE A.4

HEDONIC PRICE INDICES FOR LAPTOP COMPUTERS.
ANNUAL AVERAGE CHANGE IN THE PERIOD 1990-2000

	Semi-logarithmic						Double logarithmic					
JOINT ESTIMATION OF THE DATA POOL :												
Brand variables	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No
Cloned variable	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No
Weight variable	No	No	No	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes
Annual average change	-21.01	-18.72	-18.25	-24.73	-21.51	-20.96	-34.95	-31.75	-31.49	-32.11	-30.49	-30.1
PERIOD-BY-PERIOD ESTIMATION (a)												
Brand variables	No	No					No	No				
Cloned variable	No	Yes					No	Yes				
Weight variable	No	No					No	No				
Annual average change	-28.20	-18.91					-34.56	-37.77				

Source: Banco de España.
(a) Based on chained Laspeyres indices of the characteristics.

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