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INTERTEMPORAL PRICING AND PRICE DISCRIMINATION: A SEMIPARAMETRIC HEDONIC ANALYSIS OF THE PERSONAL COMPUTER MARKET

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Intertemporal Pricing and Price Discrimination: A Semiparametric Hedonic Analysis of the Personal Computer Market.

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Abstract

We apply a smooth coefficient semiparametric model to a unique high frequency data set to examine the intertemporal pricing of personal computers. Furthermore, we test (a) whether firms charge differential component prices for their top performance personal computers and (b) whether premium firms charge both a premium for all their computers and a premium for their top performance ones. We find nonlinear effects in the pricing of personal computer components. We also find that firms in general do not charge differential prices for the components of their top performance computers. In addition, high quality firms charge higher premia only for their most advanced products.

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INTRODUCTION.

It is well known that durable goods are characterized by intertemporal price discrimination. New books that first appear in hardcover and then as less expensive paperbacks, fashion clothes that are sold at substantially lower prices after their introduction, and the prices for personal computers which fall dramatically after their first appearance are some examples of intertemporal price discrimination. In the literature this issue has been examined theoretically, see Stokey (1979), and Kahn (1986). In this paper we examine empirically this issue in the market for personal computers (PC's hereafter). We examine, (a) the intertemporal pricing of the various PC components, (b) whether firms charge differential component prices for their top performance PC's over time and (c) whether high quality firms charge both a premium for all their computers and a premium for their top performance PC's as time passes. To carry out the analysis we apply a semiparametric regression approach to a unique high frequency data set.

The market of PCs is a very dynamic market. Very rapid changes in technology allow for new computer models and improved computer components to enter the market very frequently. Steady improvements in the clock speed of the processor, improvements in the size and the quality of the monitor, the appearance of the CD-ROM drive and the multi-media kit account for continuous improvements of the PCs over time. Very often, one firm offers one model and soon after it offers the same model with a better monitor or more hard drive or both. At each period firms offer for sale computers of different quality. The implicit prices of the various components of the personal computes change over time and as a result, given that a computer can be considered as a bundle of its main characteristics, any analysis of the pricing of personal computers should take into account the dynamics of the market. The time dimension that affects the pricing of the many components that make up the final price of the PC suggests the presence of nonlinear effects that are not easy to be captured empirically by standard linear hedonic specifications that are traditionally used in this case. It is for this reason that semiparametric techniques which are flexible in specific desired directions (e.g. time as in our example) are ideal for the study of pricing of PC's.

We follow a hedonic analysis, where a product is considered to be a bundle of its characteristics. Thus, in a hedonic regression, the (equilibrium) price of a product is considered to be a function of the implicit prices of its characteristics, see Triplett (1989). However, since there is no general theory suggesting a particular functional form for the hedonic regressions, one has to demonstrate that the specification adopted holds against all plausible alternatives. For example in the case of the PC market, if one were to ignore the presence of nonlinearities that affect the implicit prices of the main components over time, then the results obtained from such hedonic analysis would be misleading. In order to deal with this problem we will resort to semiparametric methods that allow for a degree of robustness against certain nonlinear alternatives. There has been considerable interest in econometrics in developing models that incorporate both parametric and nonparametric components. The regression relationship is usually expressed in terms of variables that are known to interact with the dependent variable in a specific way and they enter parametrically and those that enter non-parametrically since there is no a-priori reason for them to follow a particular pattern. The semiparametric approach offers a useful compromise between parametric and fully nonparametric methods. Hence, semiparametric estimators tend to share some of the desirable properties of both these extreme environments, that is parametric rates of convergence to their true values and a certain degree of robustness against functional misspecification, see Robinson (1988). Furthermore, they offer a compromise that to some extend alleviates the 'curse of dimensionality' problem that plagues full fledged nonparametric estimation, since the dimensionality of the unknown part of the model is now lower. The smooth coefficient model that is adopted here as a special case of a varying coefficient model offers a particular way of combining parametric and nonparametric components, see Fan and Zhang (1999) and Cai et al (2000a, 2000b).

In this paper we will estimate a smooth coefficient semiparametric hedonic model using a unique monthly data set that was collected from the PC Magazine, the main source of price information for the buy-direct segment of the PC market. The number of observations (more that 6000) allows us to uncover rich intertemporal patterns (month by month) of behavior for the various implicit price elasticities of the various components. We find that the price of clock speed decreases over the period, whereas hard drive and RAM cover together a constant proportion of the price of a PC. Screen size is an important factor of the price and there is evidence that new screens are sold at a premium upon their introduction. Moreover, we test whether generic firms price dicsriminate. We do not find evidence for that since these firms charge the same implicit prices for the PC components of all the processor types they sell. Finally, we test whether premium high reputation firms (such as IBM and COMPAQ) charge both a premium for all their products and for their top performance PC's. We find evidence that the premium firms sell only their top of the line products (as measured by clock speed) at higher premia.

The paper is organized as follows. In the next section we present a detailed description of the data. This is followed by a presentation of the smooth coefficient semiparametric regression model as it applies to the PC market. We proceed to discuss our empirical findings by first examining the results from a benchmark parametric hedonic model followed by the results from the semiparametric approach. In the next section we investigate possible differing pricing behaviors first among generic firms alone and then between generic and premium firms. Finally we conclude.

DATA.

Our source of data is the PC Magazine. This is one of the leading magazines for personal computers and thus, it is the main source of price information for the buy direct segment of the market. We collected data on the first issue of every month from January of 1993 to November of 1995.[1] These are the last three years for the 486 PCs. Around the middle of this period we have the appearance of the Pentium computers, that replaced the 486 PCs. Each observation consists of the advertised price and features of personal computers. We limited our attention to the following 10 firms: ACER, AUSTIN, COMPAQ, COMTRADE, DELL (excluding the DELL Optiplex models since this product line is targeting the business market) GATEWAY 2000, IBM, MICRON, MIDWEST MICRO, and ZEOS since these are the most frequently advertised firms. Notice that we only collected the list prices as they appeared in the ads of the above manufacturers. We thus did not incorporate prices listed by computer wholesalers. Further, we did not include price quotes for non-MIDWEST MICRO computers that were listed in MIDWEST MICRO advertisements. The collection of list prices can be justified since, for this segment of the market, list prices are essentially equal to transactions prices for purchases by individual consumers.

An observation consists of the price of a 486 based computer and its associated features. These are: the clock speed (in MHz) of the 486 processor, the size of the hard drive (in MB), the size of the RAM (in MB), the size of the screen (in inches), the presence of a CD-ROM, the presence of a multi-media kit that includes speakers and a sound card, and a dummy indicating whether the manufacturer was a "premium" firm (IBM or COMPAQ). We also use in the analysis the total number of 486 price listings for each month, and a dummy variable indicating the existence of ads for Pentium PCs.

[1] There are no ads for 486 PCs on December 1995.

We did not collect all information that indicated quality differentials between listings, both across firms and time. For instance, we did not include information on the speed of the CD-ROM or the access time of the hard drives. We also did not collect any information on bundled software, bus slots, chipset design, and delivery time. Systematic differences in these features between the premium firms and the rest will be captured by the premium firm dummy. Furthermore, improvements in quality for the same component for all firms over time will be captured by the monthly increases in the implicit prices for this component.

In every advertisement, each firm lists the price and all the features for a number of models. In a number of cases, in the same advertisement, the firm also lists the incremental price of upgrading some features on these "base" models. Every possible combination that involved an upgrade of a major component has been used to create a separate observation.[2] Moreover, we also included upgrades that incorporated a better technology when this was also associated with an increase in the price, even though these technologies are not easily quantifiable and, therefore, can not be controlled for in our regressions. Incorporating these upgrades contributes essentially to the error term, as the value of the right hand side variables is the same for these observations.[3] Our data-set consists of $6,259$ observations. The descriptive statistics for our data-set are given in Table 1.

[2]Notice here that we did not include upgrades or computers of 124 MB or more of RAM, 19 or more inches of monitor, and more than 4 Gigabytes of hard drive. The reason is that at that period these are likely to belong to a very different market segment. Using the same line of thought, we excluded all servers from the data-set.

[3]Notice that we did not include all the upgrades of this type, e.g., we did not incorporate upgrades in the keyboard of MIDWEST MICRO.

THE SMOOTH COEFFICIENT REGRESSION MODEL OF THE PC MARKET.

As it was argued in the introduction, technological improvements in the PC market are very rapid and happen very frequently in the primary processor as well as in the secondary component markets. With regard to the latter, these changes occur independently over time by the various firms that provide these components to the PC manufacturers. Thus, any analysis of the pricing of personal computers should take into account that the implicit prices of the various components of the personal computes change over time. Since these improvements are independent from each other, they can not be captured by a single time shifter (dummy variable). In other words there is evidence that the way that each component affects price is fairly nonlinear.

There are also many strategic aspects on the pricing of personal computers by various firms. For example, with the rapid technological improvements that are taking place, the introduction of a more advanced computer or component will push the prices of the old computer or component down. Moreover, computer prices of premium firms with high reputation tend to further fall over time, since the market perception about the ability of generic firms to provide a product of similar quality improves as time passes. In our analysis we allow the implicit prices of the various components to change over time. In fact we allow for a specification that captures the smooth evolution of the marginal effects of the variables in the hedonic functionn (a) intertemporally (b) both intertemporally and across PCs of different performance and (c) both intertemporally and across brands of different quality.

Let y_i denote the PC price, and let x_i be a $p \times 1$ vector of PC components that enter the hedonic function (both continuous and discrete) and z_i be a $q \times 1$ vector of other exogenous variables (such as time) that may affect the behavior of the main components. Consider the following model

$$y_i = \alpha(z_i) + x_i^T \beta(z_i) + \varepsilon_i = (1, x_i^T) \begin{pmatrix} \alpha(z_i) \\ \beta(z_i) \end{pmatrix} + \varepsilon_i \tag{1}$$

$$y_i = X_i^T \delta(z_i) + \varepsilon_i$$

where $\delta(z_i) = (\alpha(z_i), \beta(z_i)^T)^T$ is a smooth but unknown function of z. In the appendix we discuss how this function can take specific parametric formulations (such as linear) which can be tested against the general unknown specification. One can estimate $\delta(z)$ using a local least squares approach, where

$$\widehat{\delta}(z) = [(nh^q)^{-1} \sum_{j=1}^{n} X_j X_j^T K(\frac{z_j - z}{h})]^{-1} \{(nh^q)^{-1} \sum_{j=1}^{n} X_j y_j K(\frac{z_j - z}{h})\}$$

$$= [D_n(z)]^{-1} A_n(z)$$

where $D_n(z) = (nh^q)^{-1} \sum_{j=1}^{n} X_j X_j^T K(\frac{z_j - z}{h})$, $A_n(z) = (nh^q)^{-1} \sum_{j=1}^{n} X_j y_j K(\frac{z_j - z}{h})$, is a kernel function and $h = h_n$ is the smoothing parameter for sample size n.

The intuition behind the above local least-squares estimator is straightforward. Let us assume that z is a scalar and $K(.)$ is a uniform kernel. In this case the expression for $\widehat{\delta}(z)$ becomes

$$\widehat{\delta}(z) = [\sum_{|z_j - z| \leq h} X_j X_j^T]^{-1} \sum_{|z_j - z| \leq h} X_j y_j$$

In this case $\widehat{\delta}(z)$ is simply a least squares estimator obtained by regressing y_j on X_j using the observations of (X_j, y_j) that their corresponding z_j is close to z ($|z_j - z| \leq h$). Since $\delta(z)$ is a smooth function of z, $|\delta(z_j) - \delta(z)|$ is small when $|z_j - z|$ is small. The condition that nh^q is large ensures that we have sufficient observations within the interval $|z_j - z| \leq h$ when $\delta(z_j)$ is close to $\delta(z)$. Therefore, under the conditions that $h \to 0$ and $nh^q \to \infty$, one can show that the local least squares regression of y_j on X_j provides a consistent estimate of $\delta(z)$. In general it can be shown that

$$\sqrt{nh^q}(\widehat{\delta}(z) - \delta(z)) \to N(0, \Omega)$$

where Ω can be consistently estimated[4]. The estimate of Ω can be used to construct confidence bands for $\widehat{\delta}(z)$.

The intertemporal nature of the implicit prices of the PC components is captured by incorporating the time trend as our $z-$variable in equation (1) which acts as the dynamic common factor for the hedonic components. It is the dynamic nature of this common trend for the various components that introduces certain cyclical behavior (nonlinearities) in their effect on price. We further augment the $z-$part of the model to also include other variables that capture aspects of the model that pertain to certain conjectures/hypotheses about the market structure of the PC market that need to be explicitly tested. Such variables include clock speed and the generic firm dummy. By including the speed variable as part of the z's, we are able to test whether firms price discriminate by charging higher implicit prices for the various components incorporated in their top performance PCs over time. By including the generic firm dummy we are able to test for intertemporal price discrimination by premium firms. In particular we examine both whether premium firms charge a mark up for all their computers and higher prices for their more advanced PCs. We are able to capture how the marginal effects of the variables in the hedonic function change over time and across brand quality, since we are interested in inter-temporal and quality based price discrimination. Our framework is rich enough to tackle directly questions of this type.

[4]Li et al (2001) used the above smooth coefficient model to estimate the production function of the non-metal mineral industry in China.

EMPIRICAL RESULTS: HEDONIC SPECIFICATIONS.

In what follows we will compare a parametric benchmark and an augmented parametric specification that allows for certain time effects with the smooth coefficient semiparametric specification that allows for general time effects. We will show that ignoring nonlinearities in the relationship between the various components will lead to a misspecified model with misleading results.

The linear model.

We first introduce a benchmark linear specification which will be contrasted with the smooth coefficient approach of equation (1). The linear model will follow the following specification

$$y_i = \alpha + x_i^T \beta + w_i \gamma + z_i \theta + \varepsilon_i \tag{2}$$

The dependent variable is the price of the 486-type computer. The set of independent variables includes the $X-$vector of the major hedonic characteristics that make up a computer, such as clock speed in MHz, hard drive size in MBs, the size of RAM in MBs, monitor size in inches and the dummy variables for the presence of CD-ROM and a dummy variable for presence of a multi-media kit. These variables contain the main components that affect prices and are an integral part of hedonic analysis. The $X-$vector also includes a dummy that captures the introduction of the Pentium processor in the market from February 1994 (the month where the number of Pentium price listings first reached a noticeable number of 38 by seven different firms) onwards in order to examine whether the introduction of the new more advanced product will affect the price of the 486 computers. Finally, the $X-$vector includes a dummy variable indicating whether the PC manufacturer is a high reputation firm or not. Other variables which are not directly related to PC characteristics and to brand quality are included among the independent variables in the $W-$vector. Such variable is the number of 486 price listings for each month. This shows whether aggressive advertising is associated with lower prices. Finally we have included as a separate variable the time trend, which captures the span of the 35 month period that we analyze as the $z-$variable. Since there is not a unique "right" hedonic function, in our study we follow the approach that is most often used where both the price and the continuous variables (except the time trend) are expressed in logarithmic form. Hence, the coefficients of the continuous variables indicate the price elasticity with respect to a percentage change in each of these continuous variables. In the case of the log-linear specification of equation (2), these price elasticities are assumed to be constant throughout the period. The coefficient of a dummy variable indicates the percentage price differential due to the presence of the component captured by the binary variable in question. Table 2 in its second column presents the results from the estimation of (2). The variables are all very significant and at a first glance it would appear that equation (1) is an adequate hedonic specification. However, if we estimate an augmented version of equation (2) to include all the interactions of the hedonic components with the time trend as additional variables except for the number of price listings, we observe that all these interaction terms are also statistically significant. The implication is that the effect on price in percentage terms of the continuous hedonic characteristics change at a constant rate over time (see the fourth column of Table 2). This suggests that the original version of (2) was misspecified and as such inadequate as a hedonic specification.[5] In fact we conduct a test of functional form of equation (2) against the semiparametric alternative given in equation (1) as well a test of the augmented version of equation (2) against (1). We describe briefly

[5]A fully flexible parametric specification would allow for the interaction of all the hedonic components with montlhy dummies. That would introduce an enormous number of new parameters to be estimated.

the mechanics of this test in the Appendix. The test results are given in Table 2 and suggest that both the simple and augmented versions of (2) are rejected. The reason for that is that neither the simple version of (2) nor its augmented version, allowing only for simple interactions, are rich enough to capture the nonlinear time dynamics of the hedonic effects on price. Below we will allow for these dynamics to be captured fully by estimating the semiparametric hedonic equation (1).

The smooth coefficient model.

We now present the hedonic smooth coefficient regression counterpart of the linear regression equation (2). The equation of interest is a simple extension of equation (1) where we also add a component to the model that contains information that is not considered to be of the hedonic type and as such not directly affected by z. The model that we estimate is given by

$$y_i = w_i^T \gamma + x_i^T \beta(z_i) + \varepsilon_i \tag{3}$$

We will analyze a model that tries to explain prices of 486 computers by using a number of different characteristics. As in the case of the linear specification of equation (2) in the previous section, we include in the $X-$ vector the major hedonic characteristics such as clock speed, hard drive size, the size of RAM, monitor size and the dummy variables for the presence of CD-ROM the presence of a multi-media kit, a dummy for the manufacturer type (whether it is a premium firm such as IBM or COMPAQ) and a dummy indicating the introduction of the Pentium processor in the market. The independent variables that enter the $W-$vector is the number of 486 price listings for each month.[6] The time trend which captures the span of the 35 month period that we analyze makes up the $z-$variable and acts as the dynamic common

[6]We also tried the number of price listings variable as part of the $X-$set of variables. However, a graphical inspection of its coefficient showed no variation over time.

factor for the hedonic components. It is the dynamic nature of this common trend for the various components that potentially may introduce certain cyclical behavior (nonlinearities) in their effect on price. Equation (3) closely resembles the structure of the linear specification given in equation (2). The only difference stems from the direct link of the coefficient vector β on the time trend in (3). That allows for a rich intertemporal analysis of the hedonic components something that was not possible in the linear case. In particular for the continuous hedonic variables we are able to analyze the behavior of intertemporal elasticities (the variables are expressed in logarithmic form), whereas for the binary characteristics we are able to display a multiplicative factor effect on price over time due to the presence of the characteristic in question. The graphical presentation of the $\beta-$coefficients is presented in Figures 1 to 2. Figure 1 presents the results for all the main continuous characteristics and Figure 2 the results for the binary variables. Certain features emerge from the results.

Firstly, the clock speed effect on price seems to follow a downward trend over the entire period. Hence, it seems that the rapid developments in computer speed technology tends to contribute to decreasing computer prices over the same period.

Secondly, the effects of hard drive and RAM are also positive on the price of the computer. It is worth noting that their overall effect on price is fairly constant over the period, even though individually the coefficients of these two components fluctuate over the period. Their fluctuating behavior seems to go in opposite directions and as such their overall effect on price remains fairly constant. This suggests that hard drive and RAM cover a constant proportion of the PC price in that period.

Thirdly, the price elasticity of screen is positive and increases over the period with some peaks and troughs. This increase may be explained by the fact that over the period there are various screen sizes that are introduced in the market at different intervals. The newer and larger screens tend to be sold at a premium and as such they tend to push the price effect of the screen component temporarily higher. Also, in general this effect is more pronounced than any of the of the other components.

Fourthly, the inclusion of CD-ROM and the multi-media kit have a small positive effect on price during the period. This is to expected since the technologies supporting these features were in their infancies and were not developed with the 486 computer model in mind. All variables are statistically significant for almost all periods, except for the multi-media kit that was not significant for 19 out of the 35 periods. Results for the continuous variables are presented in Figure 1 and for the dummy variables in Figure 2.

The introduction of the Pentium in the second half of the time period that we examine does not seem to be a large factor and its influence on the 486 price is negligible. Clearly this is because the introduction of the Pentium only takes place gradually around the middle of our period and becomes more prevalent only later on, in the second half of the period. In 9 out of 23 periods it is not significant whereas in 9 periods it is negative and significant and in 5 periods it is positive and significant. Below, we pursue this point further where we test formally whether the introduction of the Pentium brought about a structural shift in our specification. We use a nonparametric poolability test due to Baltagi, Hidalgo and Li (1996) designed for applications in panel data. However, it can be also used as a general test for structural change, where the null hypothesis is defined as the same model before and after the introduction of the potential break point (e.g. the introduction of the Pentium). The test statistic is distributed as a standard normal variate under the null hypothesis of no structural break, see Baltagi, Hidalgo and Li for details. The test statistic for the introduction of the Pentium is 0.8671 strongly suggesting evidence in favor of the null hypothesis. For this reason, in what follows, we will include the Pentium dummy as part of the $W-$vector.

The coefficient for the generic firms is negative suggesting that the premium firms sell more expensive PCs. Furthermore, the coefficient fluctuates since its value is smaller in absolute terms at the beginning and the end of the period and larger in the middle. We formally test for the equality in the behavior of the two firm types using the poolability test by Baltagi, Hidalgo and Li (1996) that we employed earlier for the introduction of the Pentium. The test statistic is 3.7531 strongly suggesting the rejection of the null hypothesis.

TESTING FOR PRICE DISCRIMINATION.

It is well known that a monopolist can increase its profits by adopting a price discrimination scheme,[7] when resale of the product is difficult and consumers can be successfully separated, see Tirole (1988). Price discrimination can also occur in multi-firm markets (see Shaked and Sutton (1982) for a theoretical analysis). A number of studies have examined the issue empirically. For example, Shepard (1991) investigates price discrimination between full-service and self-service gasoline stations and Clerides (2002) between paperback and hard copy books. Verboven (1999) examines discrimination in the automobile market for automobiles with extra engine power. Testing for price discrimination is often very difficult since it is far from trivial to identify the source of price differences. These may arise due to genuine price discrimination or to differences in the costs of production. This is not the case in the PC market, since the costs of production do not typically vary as all PC manufacturers buy the various components from the same producers. There is also an independent market for these components that guarantees that their manufacturers do not price discriminate among their different customers.

There are several issues concerning price discrimination in this industry. The first is whether firms charge differential prices for their most technologically advanced products (the ones that are on the technological frontier). Since a PC is essentially a

[7] In this section we are refering to second degree price discrimination since PC manufacturers cannot separate consumers in terms of their observable characteritics.

bundle of its various components price discrimination would imply differential implicit prices for these components for different computer types (as measured by clock speed). On the other hand, the presence of an independent market of PC components where anyone could upgrade his or her computer would work against this hypothesis.

The second issue concerns price discrimination by premium firms. There is a conjecture that premium firms do not charge differential prices for their most technologically advanced PC's and that their higher overall computer prices reflect the superior service that they provide to their customers and the reputation that they have acquired as a result in the market. Under this assumption, the premium they demand should be the same for all their products. However, it is also possible that high quality firms ask both for a premium for all their products, and a premium for their products on the technological frontier. In what follows we will directly test the above conjectures and we will further check how they hold over time.

Price discrimination for the PC components.

Under the hypothesis that consumers who prefer top performing PCs are also willing to pay an additional premium to acquire them, we would expect that the implicit prices for the PC components will be higher for the more advanced computers as measured by clock speed in MHz. Hence, implicit prices for PC components would diverge as clock speed increases.[8] On the opposite side, since consumers can buy additional hard drive and/or add a multi-media kit on their computer by themselves, the above argument of higher implicit prices for PC's with higher clock speeds is mitigated. In order to avoid price differences that arise due to differential beliefs

[8] This analysis does not allow us to get the implicit prices for clock speed. Therefore, we can not test for price discrimination based on the pricing of clock speed.

that consumers may hold about firm quality, we only use data on the sub-group of non-premium (generic) firms. These firms are of similar quality and reputation and consequently they charge the same brand premia over the period we examine, see Deltas and Zacharias (1999). Table 3 below, presents a short description of the data that belongs to this subgroup of generic firms.

To test the above hypothesis we incorporate clock speed as part of the z's in equation (3). This allow us to get a set of implicit price coefficients for all variables in X for each processor type in each month. Therefore, we can then test whether the implicit prices of the components remain the same as speed increases. Our results suggest that the implicit prices for all PC components are essentially the same for all different speed 486 processors and any differences are negligible. In fact the implicit prices for RAM, screen and the multi-media kit seem to be smaller for the 66 MHz than the 33 MHz computers. These results are robust and hold over time for all processor types and for all components. When the implicit prices for a component changes with time, that price change occurs simultaneously for all processor types. Hence, it seems that PC manufacturers are effectively constrained by the parallel PC components market and do not price discriminate. For expositional purposes, in Figures 3 and 4 we present the implicit prices of RAM and CD-ROM respectively for the three most often advertised models in terms of clock speed.

Price discrimination for the premium firms.

We have shown that premium firms charge higher prices for their products. Within the smooth coefficient model framework we are able to test both whether high quality firms charge a premium for all their products (reflecting an overall superior product quality and superior service they provide to their customers) and also whether they sell their most technologically advanced products at a premium, reflecting the higher willingness to pay for these products by consumers. If only the first case occurs, we have evidence that premium firms do not price discriminate. On the other hand, in the second case we have evidence that premium firms price discriminate.

To test the above hypothesis, we include the firm dummy as part of the z's in equation (3). This allow us to get implicit price coefficients for all variables in X for both premium and generic firms for each month. Incorporating both continuous and discrete variables in kernel regression is achieved using the mixing of kernels designed to deal separately with each type of variable, see Racine and Li (2001).

Intercept differences in the smooth coefficient specification allow us to test whether on average high quality firms charge a premium for all their products, both for those with lower and higher speeds. In addition, a positive difference in the speed coefficient (the most fundamental PC component) between the two groups will suggest that as the speed of the PC increases, the price difference between generic and premium firms also increases. The same interpretation holds for the other components as well. However, since these components are not as important and since there is a parallel components market, one would expect less pronounced differences between the premium and generic firms than the ones that could be found for clock speed.

Due to the relatively small number of observations for the premium firms (612 obs), the comparison is meaningful for only 13 months, from August 1993 to August 1994. The evidence regarding the intercept is mixed. Initially it is positive but it turns negative shortly after.[9] This suggest that premium firms do not sell their products at a mark up. As expected, we have mixed evidence for the continuous variables The differences for the CD-ROM coefficients are positive throughout the period. The differences for the multimedia kit coefficients are mostly positive. However, what is most important to see is the variable for speed. The coefficients for speed are always

[9]Intercept differences are significant when positive and insignificant for most of the periods when they are negative, whereas differences in the speed coefficients are significant for most periods.

higher for the premium firms.

This is evidence that premium firms price discriminate by selling their top performance PCs at a premium. The difference between the two coefficients for speed ranges from 0.037 to 0.157. This suggests that the premium for a 66 MHz processor by high quality firms is from 2.6 to 11.5 percent higher than the premium for the 33 MHz processor. The results are presented in Figures 5 and 6 for the two intercepts and the two clock speed coefficients respectively.

CONCLUSION

Changes in the market for personal computers are very rapid and occur very frequently. For this reason the use of parametric techniques to examine this market is not appropriate since the latter fail to capture the nonlinearities that arise over time. In this paper we used a smooth coefficient semiparametric model to examine the intertemporal pricing of the PC components. We also tested whether PC manufacturers charge higher component prices for their top performance PCs. Finally, we tested whether high quality firms charge both a premium for all their products and a premium for their top performance PCs. The results support the nonlinearity hypothesis about this market. Furthermore, firms of the same quality do not price discriminate with respect to their more advanced products. However, high quality firms charge higher prices for their products in the technological frontier.

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APPENDIX

We will present below a test statistic that was used by Li et al (2001). In our implementation we will use a bootstrap version of this test. Let y_i denote the dependent variable, and let x_i be $p \times 1$ and z_i be $q \times 1$ vectors of exogenous variables. Consider the following linear model

$$y_i = \alpha_0(z_i) + x_i^T \beta_0(z_i) + \varepsilon_i = (1, x_i^T) \begin{pmatrix} \alpha_0(z_i) \\ \beta_0(z_i) \end{pmatrix} + \varepsilon_i \quad \text{(A1)}$$

$$y_i = X_i^T \delta_0(z_i) + \varepsilon_i$$

where $\delta_0(z_i) = (\alpha_0(z_i), \beta_0(z_i)^T)^T$ is a smooth known function of z.For example in the context of equation (2), ignoring for the moment the presence of the $w\prime s$, we have $\alpha_0(z_i) = \alpha + z_i\theta$ and $\beta_0(z_i) = \beta$. Similarly equation (A1) captures the case of the augmented version of (2) to allow for the simple interactions of the $x\prime s$ with z, where $\alpha_0(z_i) = \alpha + z_i\theta$ and $\beta_0(z_i) = \beta_1 + \beta_2 z$.

We can test the adequacy of (A1), the H_0, against the semiparametric alternative (1) using the following test statistic.

$$\begin{aligned} \widehat{I}_n &= \frac{1}{n^2 h^q} \sum_i \sum_{j \neq i} X_i^T (y_i - X_i^T \widehat{\delta}_0(z_i)) X_j (y_j - X_j^T \widehat{\delta}_0(z_j)) K(\frac{z_j - z_i}{h}) \\ &= \frac{1}{n^2 h^q} \sum_i \sum_{j \neq i} X_i^T X_j \widehat{\varepsilon}_i \widehat{\varepsilon}_j K(\frac{z_j - z_i}{h}) \end{aligned}$$

where $\widehat{\varepsilon}_i$ denotes the residual from parametric estimation (under H_0). It can be shown that under H_0, $J_n = nh^{q/2}\widehat{I}_n/\widehat{\sigma}_0 \longrightarrow N(0,1)$, where $\widehat{\sigma}_0$ is a consistent estimator of the variance of $\widehat{I}_n$, see Li et al (2001). It can be shown that the test statistic is a consistent test for testing H_0 (equation (3)) against H_1 (equation (1)). We use a bootstrap version of the above test statistic, since bootstrapping improves the size performance of kernel based tests for functional form, see Zheng (1996) and Li and Wang (1998).

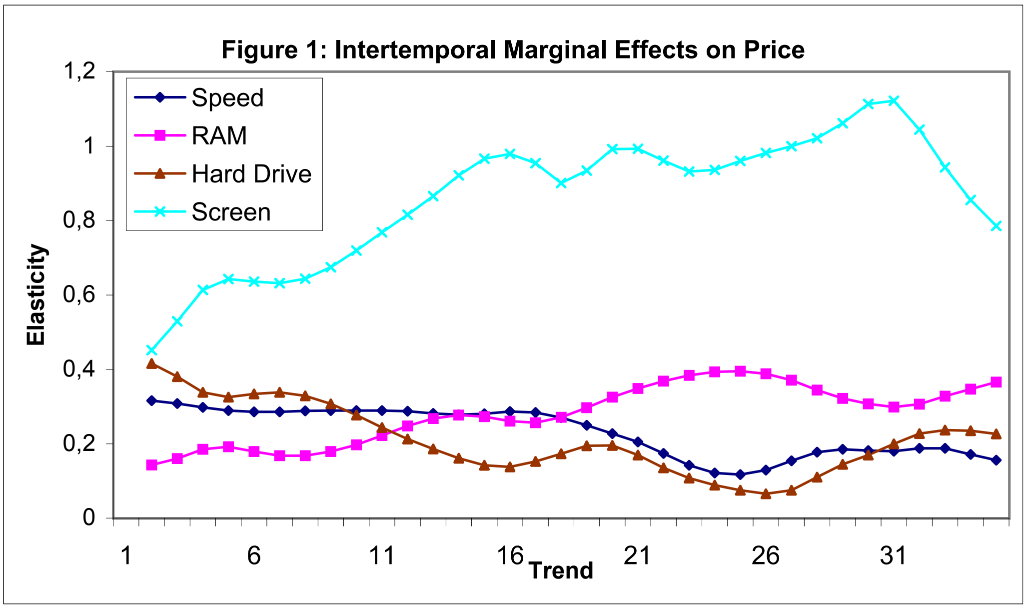
Figure 1: Intertemporal Marginal Effects on Price
Elasticity
Trend
Speed
RAM
Hard Drive
Screen
1,2
1
0,8
0,6
0,4
0,2
0
1
6
11
16
21
26
31

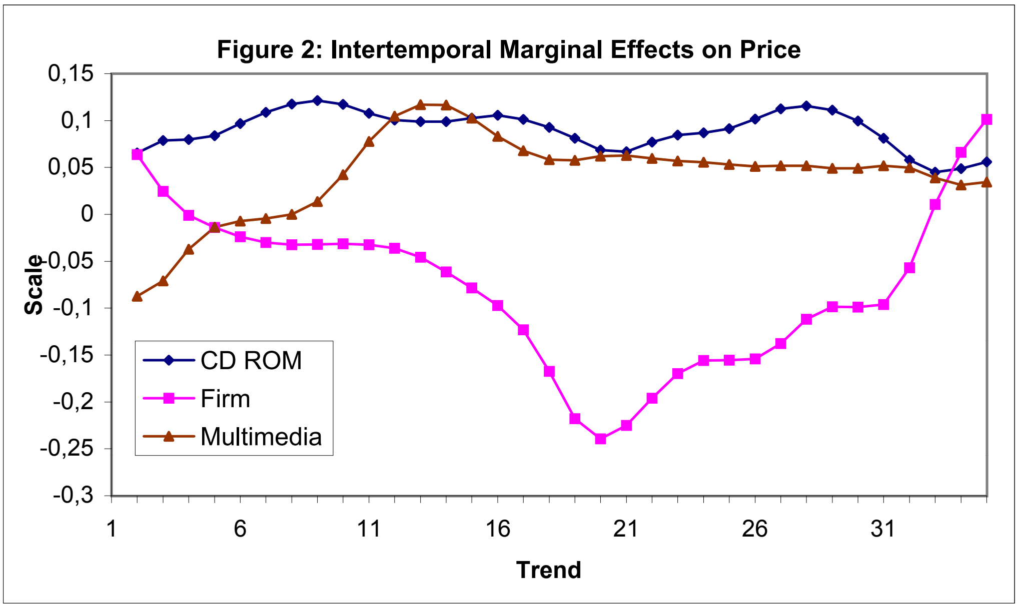
Figure 2: Intertemporal Marginal Effects on Price
Scale
Trend
CD ROM
Firm
Multimedia
0,15
0,1
0,05
0
-0,05
-0,1
-0,15
-0,2
-0,25
-0,3
1
6
11
16
21
26
31

Figure 3: Intertemporal Marginal Effects of RAM on Price

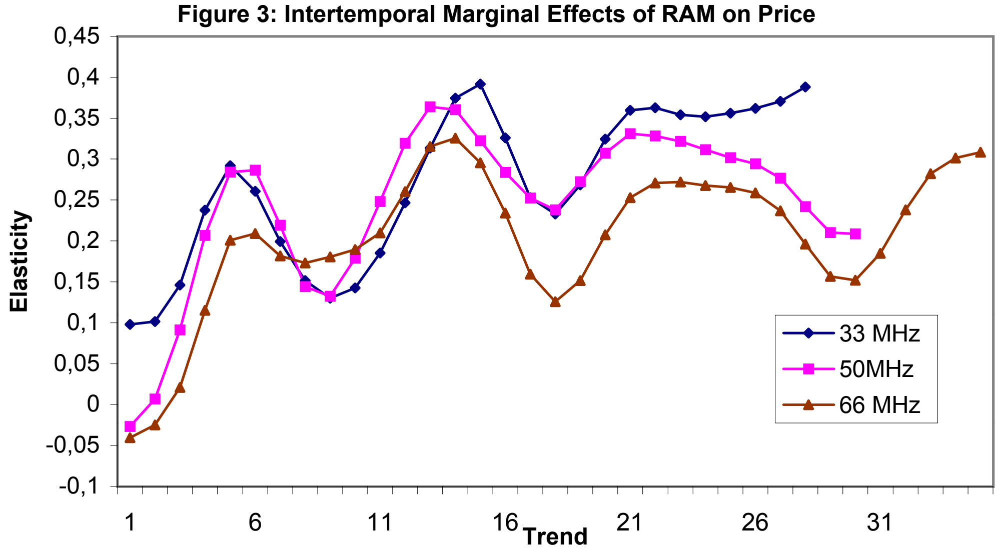

Figure 4: Intertemporal Marginal Effects of CD ROM on Price

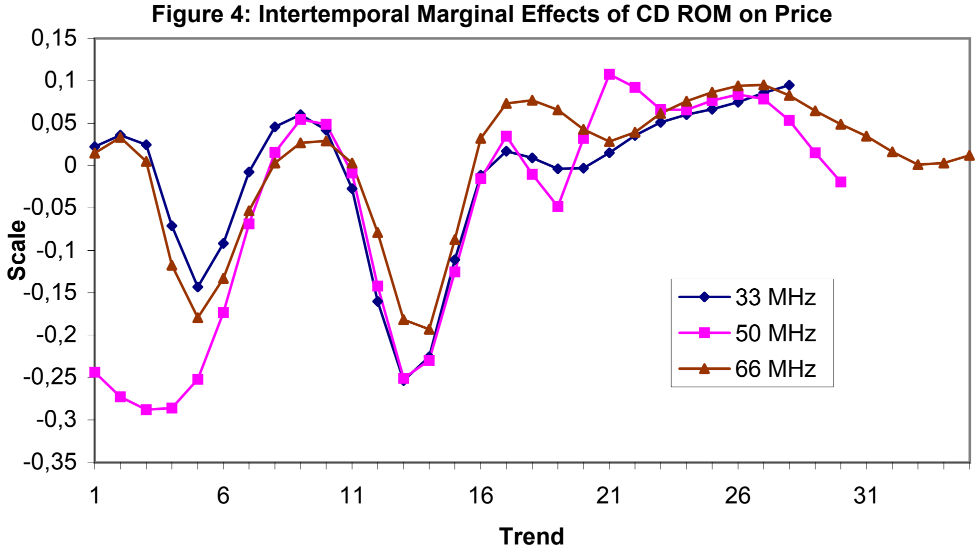

Figure 5: Marginal Effect of Intercept for Premium and Non Premium Firms

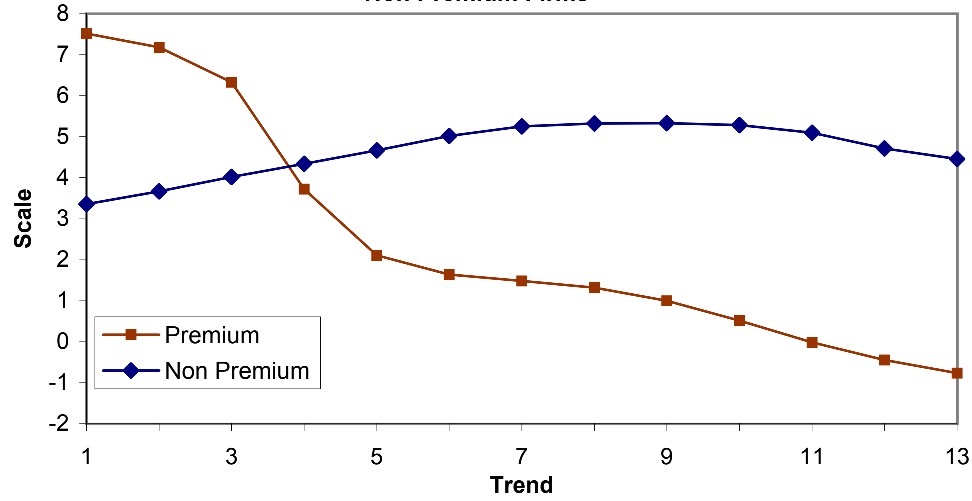

Figure 6: Marginal Effect of Speed for Premium and Non Premium Firms

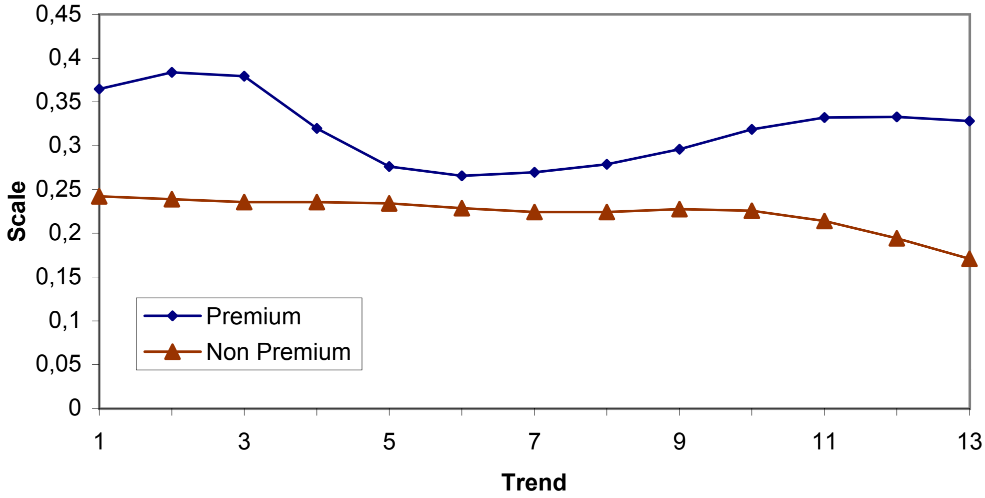

Table1: Descriptive Statistics.

Variable	Mean	Std. Dev.	Min	Max
Speed	52.011	21.1577	25	100
Hard Drive	416.6017	258.5484	80	2100
RAM	8.2869	5.6311	2	32
Screen	14.61	0.9051	14	17
CD ROM	0.4646	0.4988	0	1
Multimedia	0.1395	0.3465	0	1
Firm Dummy	0.9022	0.2970	0	1
Num. Of ads	221.301	74.835	39	339
Num. Of obs.	6259			

Table2: The Linear Model.

No Trend Interactions			Trend Interactions	
Variable	**Coeff.**	**Std. Err.**	**Coeff.**	**Std. Err.**
Trend	-0.022222	0.000416	0.021717	0.008892
LSpeed	0.208211	0.004145	0.302421	0.00981
LHard	0.143746	0.005327	0.271821	0.011257
LRAM	0.181147	0.004459	0.040757	0.00933
LScreen	0.724435	0.0264	0.589838	0.061201
DFirm	-0.231805	0.005316	-0.123968	0.014509
DCD	0.047367	0.004122	0.061985	0.009551
Dmulti	0.033327	0.004869	0.087096	0.01474
NumAds	0.000214	0.000023	-0.000168	0.000041
dPent	-0.01076	0.005634	0.04232	0.021427
Con	4.23351	0.071863	3.7085	0.1634
LSpeedT			-0.00568	0.000567
LHardT			-0.008208	0.000664
LRAMT			0.008873	0.000516
LScreenT			0.00775	0.003268
DFirmT			-0.007107	0.000915
DCDT			-0.001119	0.00056
DmultiT			-0.002815	0.000702
dPentT			-0.005265	0.00155
	Adj R-squared: 0.791		Adj R-squared: 0.811	

Table 3: Non Premium Firms

Speed	Observations	Months
25	431	22
30	1809	28
50	933	30
66	1861	35
75	122	14
100	491	20
Num. Of obs.	5647	

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