Valuing Mobile Computing:
A Preliminary Price Index for PDAs*

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Introduction

In the twenty years since IBM introduced the PC, three major dimensions of technological development have been apparent in "personal" computing hardware. First, and most visibly, the computational power and storage capacity of microcomputers have increased at a geometric rate that shows no sign of slowing, and may even have accelerated in recent years. Second, a wide variety of peripheral and interface devices have been introduced, ranging from higher resolution monitors to DVD drives to network equipment. Third, since the introduction of the Compaq Portable in 1982,[1] mobile computers have been steadily shrinking in size and weight, while tracking important aspects of the performance and functionality of desktop machines.[2] All three of these trends have significantly affected the adoption and use of computers, as well as their diffusion into many areas of social and economic interaction. Notably, only the first dimension has received significant attention from social scientists seeking to quantify the impact of technological change in IT.

We focus here on the third of these technology trends – the increasing portability of computing devices. By freeing a device from a specific location, portability confers significant benefits to the user. These benefits come from a variety of sources, for example more efficient use of time through the ability to work in transit or at remote locations, the ability to deliver or receive location-sensitive data, or simply the ability to use a device in a more convenient or congenial environment. As advances in wireless networking and the functionality of mobile devices usher in an era of ubiquitous "always-on" computing, portability seems likely to play an even more important role in driving IT's ability to augment individuals' lives.[3] But just how large are these benefits, and how have they been changing over time as technological progress and intense product market competition have made mobile computers simultaneously cheaper and more powerful?

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[1] Arguably the first portable computer was the IBM 5100, introduced in 1975, or the Osborne in 1981, but the Compaq was the first PC-compatible "portable" – actually a "luggable" at 28 pounds!

[2] Considerable engineering effort has been directed at increasing the portability and performance of mobile devices; compare a typical laptop available in 2000 to 1982's Compaq Portable. Over this time period, a typical laptop shrank an order of magnitude in weight and volume, yet provided two to three orders of magnitude more computing power, a much larger, higher resolution color screen, and was able to run at peak capacity for several hours on internal batteries instead of requiring AC power.

[3] Indeed, sales of laptop and palmtop devices continued to grow strongly even as worldwide PC sales shrank for the first time in 2001. However, palmtop devices, along with desktop devices, fell in total sales in 2002, although growth is expected to resume in 2003 (Gartner, 2003).

The first place to look for answers to these questions about the value of portability to consumers is in data on prices and sales of mobile devices.[4] Market indicators suggest that the value that users derive from mobile computing is very high. The diffusion of this technology has been both rapid and extensive: laptop, palmtop and other mobile computing devices have become increasingly popular, currently accounting for over 1/3 of new computer sales in the US. At the same time, consumers appear to be willing to pay a substantial price premium for a mobile device relative to a stationary device with the same computation and storage capacity: One study found that laptop buyers were willing pay more than 2.5 times the price of a comparable desktop PC.[5]

Surprisingly, relatively little is known about the economic aspects of portability. One critical issue affecting access to portable technology and the gains to individuals and to society from innovation in this dimension is prices. While much effort has been put into understanding trends in pricing of personal computers, in particular the relationship between prices and technological characteristics, these studies have largely downplayed or ignored portability. Over the past decade, quality-adjusted prices of laptop computers appear to have been falling at rates that are comparable to desktops, but it is unclear how to interpret this evidence. Portable computers are a classic instance of the “new goods” problem: once introduced it is relatively straightforward to evaluate the impact of changes in price or quality of a good, but standard techniques do not account for the gains which accrue as the result of a good now being available which was impossible for consumers to purchase in the previous period. Studies conducted to date have not adequately addressed this aspect of the introduction of mobile computers, or the subsequent appearance of new features of these devices. Relatively little is known about the trade-offs users may make between portability and other functional aspects of computing devices, nor is much known about the extent to which portable devices are substitutes for or complements to stationary computers. Furthermore, portable devices are particularly challenging to analyze using the standard techniques of “hedonic” price analysis since they are significantly more technologically complex than desktops. While the price of a standard “white box” PC may largely be the sum of its parts, prices of laptops and other devices may reflect buyers’ willingness to pay a premium for more tightly integrated proprietary designs and components.

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[4] See for example Greenstein’s (1997) study of economic benefits attributable to innovation in mainframe computers, and the studies surveyed in Bresnahan and Greenstein (1998). Discussions of this approach in other contexts are Trajtenberg (1989), Hausman (1999) Nevo (2001), Goolsbee and Petrin (2001), and other papers collected in Bresnahan and Gordon (1997).

[5] Berndt and Rapport (2001)

The purpose of the current study is to take a first step toward addressing the issues raised above through the construction of a price index for personal digital assistants (PDAs), the most common form of palmtop computing. We begin by briefly reviewing the literature on measuring price change in computing platforms, with an emphasis on portable computers. Next, we describe the data on PDA's used in this study, and the trends evident in this marketplace. We conclude with an analysis of quality-adjusted price change in this market and the construction of a preliminary price index for PDAs.

Background

Ongoing technological innovation has led economists to study price and quality change in computing technology since the 1960s – pioneering studies include Knight (1966) and Chow (1967). Over the subsequent decades, research has examined mainframe computer processors, peripheral equipment, personal computers (PCs), and portable or "laptop" PCs.[6] The focus of this research has been on quantifying the rate of change in the price-performance ratio of computing technology through the construction of "quality-adjusted" price indexes. The production and consumption of computing technology are now so pervasive in the economy that computer price indexes have a measurable impact on key macroeconomic statistics such as the consumer price index (CPI), real GDP and productivity growth rates.[7]

The traditional approach to measuring price change in the face of quality change is the matched-model technique. As with all approaches, observations on the prices and attributes of a number of goods are made at periodic intervals. When the same "model" (i.e., a good having exactly the same attributes) appears in two time periods, any difference in the prices for the model must be due to pure price change, as there is no quality change. In this traditional approach, price indexes are constructed using the ratio of prices of the models that are "matched" across time periods. However, products characterized by rapid technological change have a high frequency of the introduction of new models and the discontinuation of old models; in this setting, there will be relatively few "matches" across time periods, and the matched model method becomes subject to a number of biases.

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[6] This literature is reviewed more thoroughly in Berndt (1991), Triplett (1989), Berndt and Rappaport (2001), and Triplett (2001).

[7] Landefeld and Grimm (2000).

One important source of this bias is sample selectivity induced by the exiting models: discontinued models will be those whose characteristics whose value relative to nominal price have fallen the most – see Pakes (2001). Thus, the primary approach to dealing with quality change in economics is the use of a hedonic function. The hedonic hypothesis proposes that a heterogeneous good can be treated as an aggregation of homogenous attributes, i.e.,

$$P = h(c) \tag{1}$$

where P is an n-element vector of prices of models of heterogeneous goods, c is a $k \times n$ matrix of the (homogeneous) attributes, and $h(c)$ is the hedonic function.

Therefore, a complex good such as an automobile can be treated as a collection of simple attributes such as horsepower, mileage, number of seats, etc.

The use of hedonic methods dates back to Waugh (1928), who undertook empirical work relating the price of asparagus bundles to their attributes (length, color, number of stalks). The term hedonic was coined in Court (1939), in work addressing automobiles. Griliches (1961) brought hedonic methods into the mainstream by updating Court's work on automobiles, and considerably extending hedonic methods.

Rosen (1974) showed that, in general, the hedonic function is an envelope function encompassing the users' value function and the producers' cost function. As with any envelope function, the form of the hedonic function is independent of the forms of the user preferences or producer costs underlying it; instead, it is determined by the distribution of buyers' preferences and sellers' costs and strategic choices.

Triplett (1983, 1987) took the necessary step of extending index number theory from goods space to characteristics space. He showed that a hedonic price index can be thought of as an approximation of an exact characteristics subindex provided that the utility function is separable between the attributes of the heterogeneous good and quantities of other, goods. Triplett suggests three criteria for evaluating the characteristics to be included as explanatory variables in the hedonic function:

1. They are homogeneous economic variables
2. They are building blocks from which heterogeneous goods are created

3. They are valued by both buyers and sellers.

In work addressing personal computers, a considerable array of characteristics have been included in hedonic regressions; however, nearly all researchers have attempted to operationalize the performance (or "speed") along with the quantity of secondary storage. Performance has traditionally been measured using a variety of technical proxies (e.g., processor clock speed in MHz, processor word length) or, more recently, with performance benchmarks, as in Chwelos (1999) and Nordhaus (2001).

Recent theoretical work continues to explore the theory underlying hedonic functions and their use in constructing price indexes. Pakes (2001) generalizes the interpretation of the hedonic function to allow for interpersonal differences in utility over characteristics, as well as imperfect competition, thereby noting that the observed hedonic function is the result of a complex market equilibrium. Thus we should not apply either a consumer willingness-to-pay or producer marginal cost interpretation to the estimated coefficients. Rather, he argues for the use of an hedonic function in constructing "proper" price indexes, which provide an upper bound on the compensating variation required to compensate consumers for a change in prices independent of the form of the utility function. In this context, the estimated hedonic surface is simply used to impute the prices of entering and exiting goods, without regard to *how* the surface is shaped (i.e., the signs and magnitudes of the estimated coefficients).

Diewert (2001) provides an interpretation of the hedonic function based on consumer theory, ignoring the producer side of the market. Using a representative agent approach (i.e., all consumers have the same utility for characteristics), he derives a variety of functional forms, and notes which of these are consistent with consumer theory and are flexible enough to incorporate new characteristics. While there is no one preferred functional form, he notes that the linear hedonic function is not consistent with homothetic preferences.

Both Pakes (2001) and Diewert (2001) explore the similarities and differences between the hedonic approach and the matched model approach, and both papers note that the matched model suffers a number of biases (selection and new goods) when the rate of technological innovation is high. However, given data of sufficient frequency (quarterly or monthly), the matched model approach will produce an index that fairly closely approximates an hedonic index (see Aizcorbe, Corrado, and Doms (2000) for discussion and equivalent econometric versions of a matched-model index). Using scanner data, however, Silver and Heravi (2002) find significant degradation of coverage of current transactions in the sample used for matched model index construction, even when monthly data are used. Further, exiting models tended to have different rates of price change than continuing models (as measured through the hedonic residual), indicating that even high-frequency matched model approaches may still suffer from selection bias.

In addition to bias, the variance of estimated price indexes is important. While hedonic indices do not suffer the selection bias that the matched model does, both hedonic and matched model techniques have variance in their estimated price indexes due to sampling. Furthermore, the hedonic indices introduce another source of variance, estimation variance, resulting from the need to estimate the hedonic function. However, preliminary empirical evidence suggests that sampling variance accounts for the majority of variance in hedonic estimates (Pakes, 2001).

In the context of hedonic price indexes, the term “new goods” has been used to refer to two types of innovation. The first meaning refers to new models of goods that are introduced having different amounts of characteristics than existing goods in the marketplace. For example, Dell may introduce a new model of PC that has more RAM or a larger hard drive than previous models. The second meaning refers to the introduction of new characteristics. The PC market has seen the introduction of innovations such as the hard drive, portable models (i.e., laptops), CD-ROM and later DVD drives, and so on. As Diewert (2001) and Pakes (2001) point out, neither hedonic nor matched model methods account for the welfare gains from the introduction of new goods or characteristics that arise for those consumers whose valuation of a new good exceeds its price. However, Diewert (2001) suggests functional forms that are capable of handling the introduction of new characteristics. These “flexible” (e.g., quadratic or semi-log quadratic) hedonic functions also allow for the estimation of reservation prices for new characteristics, and thus estimation of the welfare gains resulting from the availability of new characteristics.

Hedonic price analysis of mobile computers

Few economic studies have focused explicitly on mobile computing devices. A number of papers have examined laptop computer pricing, but have not focused on portability *per se* (Nelson, Tanguay, and Patterson (1994); Berndt, Griliches, and Rappaport (1995); Baker (1997), Berndt and Rappaport (2001), Chwelos (1999), and Chwelos (2003)). To the extent that these studies have examined portability, it typically has been operationalized in terms of weight or volume, and confined to laptop and notebook computers rather than the full range of mobile computing devices. A number of puzzling – and interesting – results have emerged from this work: parameter estimates are unstable over time; the estimated rate of decline of quality-adjusted prices was lower for mobile computers than for desktops until the late 1990s; and coefficients on characteristics were not equal across mobiles and desktops. For purposes of comparison, we begin to address these questions through the construction of a price index for a relatively un-studied class of (very) mobile computing devices: PDAs. Future work will compare the results for PDAs to those for other mobile and fixed computing platforms.

At least since Griliches (1971), and as reemphasized by Pakes (2001), it has been recognized that hedonic regressions are only a reduced form representation of both consumer and producer optimizing behavior, and coefficients therefore cannot easily be interpreted in terms of marginal valuation or marginal cost. Nonetheless, users of this methodology in government statistical agencies and elsewhere find parameter instability troublesome. If it reflects familiar "mechanical" specification problems such as multicollinearity, measurement error etc., then parameter instability may be easy to address. On the other hand it may also be generated by economically significant factors such as failing to control for producer behavior, which could be done by instrumenting with variables that capture supply factors, such as semiconductor costs, or market concentration measures.[8] In the PC market, one salient aspect of market dynamics is changing markups over the lifecycle of generations of processor technology: much higher margins are obtained on products incorporating a new generation of processor during their first few quarters. It is possible that more stable parameter estimates (and thus more readily comparable price changes) could be obtained with a regression specification that recognizes the product lifecycle explicitly. Chwelos, for example, found relatively stable coefficients within periods of time corresponding to distinctive technology regimes (e.g. 32-bit processor, megabit DRAMs, monochrome LCD screens). One way to address this problem within the standard hedonic framework is to use regression specifications (dummy variables for "generations", interacted with characteristics such as CPU speed) to estimate "piece-wise" stable coefficients. We note, though, that this problem with unstable coefficients has thus far only been observed in models computed at annual frequency. By re-estimating these models using quarterly (or even

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[8] We note that though the number of distinct computer models sold remains high, the market has become increasingly concentrated in terms of manufacturers. Product variety may also change in important ways over the lifecycle of a technology generation.

monthly) data one would be able to evaluate "lifecycle" timing and pricing dynamics much more precisely.

Mobile computers present a challenge for traditional hedonic analysis since, in contrast to desktop computers their design is much less modular and much more integrated. Informed observers have frequently pointed out that the "output" of a computer is not necessarily additively separable on its component-level "inputs" – doubling RAM or processor clock speed will not necessarily result in a doubling of performance (or halving of execution time) in completing tasks, see, e.g., Cole et al. (1986) and Dulberger (1989), and most recently Nordhaus (2001). Differences in performance, therefore, may not be adequately captured by differences in the list of components. Chwelos examined this issue using system "output" benchmark data as a performance characteristic, as well as conventional "input" measures, such as clock speed, memory size etc., and found that (at least for desktops) the more easily observable input measures could, in combination, be used as an adequate proxy. In part this finding may reflect the scaling properties of the PC-compatible architecture, but it may also reflect the nature of the product market. With intense product market competition, many PC-compatible computers appear to be priced as the sum of component costs, assembly costs, and a very small operating margin. With homogenous technology and internal design, and highly competitive pricing, "true" performance differences may not be reflected in pricing. By contrast, mobile computers are more heterogeneous in design, contain more proprietary engineering, and rely less on standardized modular subsystems. Thus component lists may be a significantly poorer proxy for performance, and since mobile computers have historically been sold under less intense pricing pressure, and with higher margins, some of these performance differences may be visible in pricing. Some evidence for this phenomenon in other contexts can be seen in the large, and highly significant brand effects estimated in prior work examining prices of new cars, televisions and personal computers.

In addition to this performance measurement issue, users' valuation of the characteristics of mobile computers may differ from that of desktops in other important ways. Portability requirements mean that designers of mobile computers have to make quite different trade-offs, which may be difficult to fully capture using simple proxy variables. "Portability" is itself challenging to measure consistently over time. Prior studies have used "footprint", weight, volume, density, and other characteristics, but it is not clear how well these capture portability. Further refinement and testing of these measures is necessary. Furthermore, in minimizing size and weight, engineers have had to solve a variety of challenges ranging from heat dispersion and power management to resistance to mechanical and environmental shocks, miniaturization of components, etc.[9] Compared to desktops, mobile computers may therefore have much more unobserved variation in desired performance characteristics, above and beyond computational power and storage capacity. These may include power consumption, battery efficiency, reliability, ergonomic aspects of "usability", and durability. Aesthetic aspects of product design also appear to be important to users. Again, some of this variation can be captured by brand dummies, but there is no reason to assume that these should be stable over time. Modeling this unobserved component of quality is a challenge, all the more so when we consider PDAs and other handheld devices that may be built as closed systems with proprietary technology, and can be sold bundled with software applications in ROM.

One previous study, an undergraduate honors paper, has constructed a price index for PDAs (Vonnahme 2002). Using data published in magazines and buyers' guides, PDAs were found to have declined in quality-adjusted prices at an average rate of 14-18% per year over the period 1999 through the first quarter of 2002. However, the valuation of performance and mobility in PDAs remains poorly understood. Indeed, the feature set of a PDA is evolving rapidly, and definitions of what a PDA is and is not, particularly with respect to related devices such as smart phones and pagers, are unclear. The very concept of "performance" in a PDA has yet to be clearly defined.

Data

For the current study, data on the characteristics and prices of PDA's for the years 1999-2002 were obtained from Gartner, Inc. Excluding observations for which a price in US dollars was not specified left a total of 144 observations; the distribution of observations across years and brands is presented in Table 1 below. The data contained a number of missing characteristics, which were "backfilled" using a variety of sources (product fact sheets, product reviews, vendor listings, buyers' guides, etc.). Average values of key characteristics are presented in Table 2 below. Although nominal price remained nearly constant at $450 across the timeframe, there are significant trends in terms of the performance and form factor of PDAs. Over the four years, we

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[9] Critical design and technology choices advances for mobile computers include: power source (internal vs. external, weight and size, capacity, battery technology e.g., alkaline, nickel cadmium, nickel metal hydride, lithium ion, lithium polymer); processor (performance, word size, power consumption, variable speed); Heat Dispersion (radiant, fan); input technology (stylus versus keyboard); and display type (size, resolution, color, active/passive matrix, power consumption).

can see that PDAs have become smaller, lighter, and provide more colors on albeit smaller screens. Concomitantly, average battery life has fallen over the period as these machines have become significantly more powerful and made use of rechargeable rather than disposable batteries.

Increasing performance is embodied primarily through the introduction of new generations of central processing units (CPU's) that are relatively more energy efficient and operate at higher clock speed (measured in MHz). Likewise, the quantity of random access memory (RAM) and Flash ROM (read-only memory) has increased significantly over time.[10] A full description of the variables used in this study is presented in Table 3 below.

Preliminary Analysis

The base specification for estimation of the hedonic function is a log-log formulation using the explanatory variables outlined in Table 3. Perfect collinearity prevents all of the dummy variables from being included, so several are dropped, making the "reference case" PDA one that has an "other 16-bit" processor and an "other OS". Likewise, perfect collinearity between weight, volume, and density in the log-log specification requires that one of the three be eliminated, and thus weight was dropped. Finally, the total number of expansion slots is defined as the sum of the types of slots included, and the decision was made to employ the summary measure in place of identifying each type of slot since there is little expected user value or producer cost difference among the different types of slots. In addition to the characteristics outlined in Table 3, annual dummy variables for the years 2000, 2001, and 2002 were included in the regression. Results are present in Table 4 below.

Overall, the regression goodness of fit is acceptable, with an adjusted $R^2 = 0.7772$. The year dummy variables are negative, statistically significant, and increasing in magnitude in later years, indicating a negative price trend. Major drivers of price include battery type, especially the later-generation technologies lithium polymer and lithium ion, although battery life itself is insignificant. Larger screens command a higher price, although the number of colors and resolution are insignificant. For communication ports, all were insignificant except for rj11 or standard telephone slots, which are primarily present on models in earlier years. The lack of

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[10] In these machines, "ROM" is actually a misnomer, as this memory can be erased and reprogrammed to allow for upgrades to the operating system without changes to the hardware.

significance for infrared ports may be due to the fact that there is almost no variation on this dimension, as 94% of models have an infrared port.

With regard to performance, the dummy variables for the different types of processors are of varying sign and significance, while the coefficient on MHz is positive and statistically significant. Given the limited variation of MHz within processor types, there may simply not be enough variation to disentangle the impacts of clockspeed from processor generation.[11] The quantity of RAM emerges as positive and significant, while, interestingly, ROM is not. Again, this may be a result of collinearity between these two characteristics. While RAM, MHz, and processor generation (and, to an extent, OS) clearly account for some performance aspects of PDAs, this important factor is deserving of more attention in future research.

Using the estimated coefficients, a simple dummy variable price index was constructed, and is presented in Table 5 below.[12] Overall, PDAs show a rapid rate of quality adjusted price change, averaging –17.45% per year across the four years in the sample, despite almost no change in the nominal prices. Therefore, the change in quality-adjusted prices is almost solely attributable to changes in characteristics. Interestingly, the (negative) rate of price change accelerates through the sample, reaching a maximum rate of –25.4% between 2001 and 2002. This finding accords well with descriptions in the popular press, which report a more competitive environment in 2002 following the dot-com crash and reduced spending on information technology (IT) worldwide. During this time, firms focused both on bringing down the cost of existing models and aggressively introducing newer, more capable models. Since 2003 is also expected to be a lean year for IT spending, it will be interesting to see if the trend of increasing price declines continues to hold.

Conclusion

This paper has taken a first step toward building an economic valuation of mobility in computing platforms through the examination of an "ultraportable" technology: the personal

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[11] As with Chwelos (1999, 2003) interaction terms between CPU generation and MHz could be constructed to more accurately account for performance. However, given the limited variation of MHz within processor generations, this approach was not taken.

[12] The accepted correction factor of one half of the standard error of the estimates was added to the estimated coefficients to produce an unbiased estimate of the rate of price change.

digital assistant. This platform was found to have undergone significant innovation in the period 1999-2002, and fell in quality-adjusted prices at an average annual rate of –17.45% per year.

However, much work remains to be done in understanding the economics of portability. Immediate items on our research agenda include updating the frequency of price/characteristics observations to a quarterly basis, and constructing a more frequent price index to better illuminate product lifecycle issues. Work is also ongoing to produce updated and comparable price indexes for desktop personal computers as well as laptops, and to compare these three categories of computing hardware. Ultimately, inter-category demand effects will be examined with the objective of producing an "elasticity of portability" and an understanding whether these classes of computing hardware are substitutes or complements.

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Table 1: Observations by Year and Brand

Vendor	1999	2000	2001	2002
Casio	3	3	4	4
Compaq	4	2	3	5
Handspring	1	4	6	4
Hewlett-Packard	4	5	6	3
IBM	2	1	2	
Motorola				1
NEC	1	2	1	2
Palm (3Com in 1999)	6	10	8	6
Psion	4	1	2	
Research In Motion		1	2	1
Samsung				1
Sharp	9	7		
Sony			4	6
Toshiba				3

Table 2: Mean Characteristics by Year

	1999	2000	2001	2002	Total
Nominal Price	$495.97	$458.11	$408.39	$466.00	$455.90
MHz	56.15	59.86	75.00	134.83	81.72
RAM (MB)	11.15	11.81	14.71	31.25	17.28
Flash ROM (MB)	6.68	6.02	7.74	16.75	9.31
Pixels (display resolution)	88,094	69,688	59,284	75,022	72,622
Display size (diagonal inches)	4.98	4.47	3.79	3.62	4.20
Colors	11,732	11,514	17,058	42,910	20,878
Weight (ounces)	11.37	9.89	7.10	6.87	8.75
Volume (cubic inches)	21.29	17.28	11.23	11.36	15.15
Battery life (hours)	536.97	534.41	464.08	367.78	474.80

Table 3: Variable Descriptions

Variable	Description
disarm	Dummy for Intel SideARM processor (110, 1000, 1100)
dipxa250	Dummy for Intel PXA250 processor
dnecvr1	Dummy for NEC VR processors (4111, 4121, 4131)
dnecvr2	Dummy for NEC VR 4122 processor
ddbv13	Dummy for Motorola DragonBall processors (DragonBall, EZ, VZ)
ddbv4	Dummy for Motorola DragonBall Super VZ processor
darm7	Dummy for
dother16	Dummy for other 16-bit processor
dother32	Dummy for other 32-bit processor
dti710	Dummy for Texas Instruments OMAP 710 processor
dpalmOS	Dummy for Palm operating system
dotherOS	Dummy for other operating system
dwinOS	Dummy for Windows (CE, Pocket PC) operating system
dIR	Dummy for infrared port
dserial	Dummy for serial port
dUSB	Dummy for USB port
drj11	Dummy for rj11 (telephone) port
dblue	Dummy for Bluetooth wireless support
dWIFI	Dummy for WiFi (802.11b) wireless support
dmemstik	Dummy for Sony Memory Stick expansion slot
dsdmmc	Dummy for Secure Digital or Multimedia Memory Card expansion slot
dcf	Dummy for Compact Flash expansion slot
dpcmcia1	Dummy for PCMCIA type I expansion slot
dpcmcia2	Dummy for PCMCIA type II expansion slot
dsmartc	Dummy for Smart Media expansion slot
Slots	The total number of expansion slots
dphone	Dummy for cellular telephone capability
dcradle	Dummy for a docking cradle
dalk	Dummy for disposable alkaline batteries
dlipoly	Dummy for rechargeable lithium polymer battery
dnimh	Dummy for rechargeable nickel metal hydride battery
dbliion	Dummy for rechargeable lithium ion battery
MHz	Clock speed of the CPU, measured in millions of cycles per second
RAM	Quantity of random access memory measured in megabytes (MB)
ROM	Quantity of flash read-only memory measured in MB
Colors	Number of colors supported by the display
Pix	Number of pixels in the display
Weight	Weight of the PDA in ounces
Dense	Density of the PDA, in ounces per cubic inch
Volume	Volume of the PDA in cubic inches
Bat	Claimed battery life in hours
Screen	Screen size, measured diagonally, in inches

Table 4: Hedonic Regression Results, ln(price) dependent variable

Variable	Coefficient	Std. Error	t-stat
d2000	-0.1280	0.0610	-2.10
d2001	-0.3225	0.0811	-3.98
d2002	-0.6343	0.1175	-5.40
disarm	0.2492	0.1103	2.26
dipxa250	0.2236	0.2292	0.98
dnecvr1	-0.1443	0.0888	-1.62
dnecvr2	-0.1564	0.1466	-1.07
ddbv13	1.0905	0.3153	3.46
ddbv4	1.0336	0.3668	2.82
darm7	0.0581	0.1866	0.31
dother32	0.6267	0.1216	5.15
dti710	0.4329	0.3027	1.43
dpalmOS	-1.0166	0.3250	-3.13
dwinOS	-0.6783	0.2115	-3.21
dir	-0.2285	0.1177	-1.94
dserial	-0.0229	0.0723	-0.32
dUSB	0.0009	0.0876	0.01
drj11	-0.3988	0.1606	-2.48
dblue	0.1236	0.1938	0.64
dWIFI	-0.1215	0.3031	-0.40
lnSlots	0.1838	0.1049	1.75
dphone	0.1104	0.1680	0.66
dcradle	0.0484	0.0536	0.90
dlipoly	0.3988	0.1244	3.21
dnimh	-0.0586	0.1784	-0.33
dbliion	0.2979	0.0844	3.53
lnMHz	0.2425	0.0998	2.43
lnRAM	0.1168	0.0497	2.35
lnROM	0.0406	0.0468	0.87
lnColors	0.0135	0.0096	1.41
lnPix	-0.0623	0.0753	-0.83
lnDense	0.3693	0.1677	2.20
lnVolume	0.3855	0.1047	3.68
lnBat	-0.0036	0.0222	-0.16
lnScreen	0.7045	0.2801	2.52
constant	4.0519	0.8463	4.79

Table 5: Price Index for PDAs

Year	Index	Change
1999	1.000	
2000	0.907	-9.29%
2001	0.754	-16.85%
2002	0.562	-25.44%
	CAGR	-17.45%