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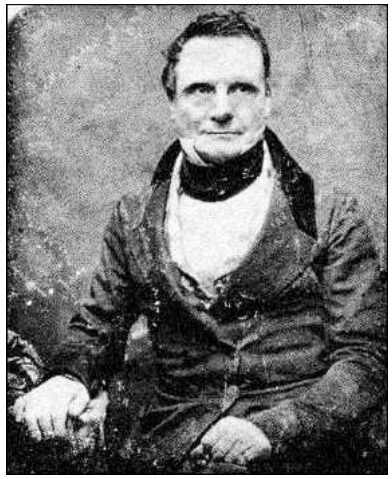
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MEASURING THE WELFARE GAIN FROM PERSONAL COMPUTERS

by

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Measuring the Welfare Gain from Personal Computers

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Abstract

The welfare gain to consumers from the introduction of personal computers is estimated here. A simple model of consumer demand is formulated that uses a slightly modified version of standard preferences. The modification permits marginal utility, and hence total utility, to be finite when the consumption of computers is zero. This implies that the good won't be consumed at a high enough price. It also bounds the consumer surplus derived from the product. The model is calibrated/estimated using standard national income and product account data. The welfare gain from the introduction of personal computers is about 4 percent of consumption expenditure.

Keywords: Computers, Technological Progress, Welfare Gain

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1 Introduction

What is the welfare gain to consumers from the development of and improvements in personal computers (PC's)? This is the question addressed here. The answered offered is that welfare increased by approximately 4 percent, measured in terms of total personal consumption expenditure, due to the introduction of the PC. This finding is obtained by employing a model of consumer behavior based upon more-or-less standard preferences, which is fit to aggregate national income and product account data using a direct and simple calibration/estimation strategy.

To estimate the welfare gain from the introduction of a new product one must know what utility is in the absence of the good. A conventional isoelastic utility function has two problems. First, at zero consumption the utility function returns a value of minus infinity whenever the elasticity of substitution is less than one. In this case the welfare gain from the introduction of the new good is infinitely large. Second, marginal utility at zero consumption is infinite, so long as the elasticity of substitution is finite. Therefore, consumers will always purchase some of the good in question, no matter how high the price is, albeit perhaps in infinitesimal quantities. To avoid these problems a form for preferences will be adopted that gives a finite level for marginal utility, and hence one for total utility, at zero consumption. With this utility function, high prices may result in the consumer optimally choosing to purchase zero computers. In addition, the consumer's surplus associated with the introduction of a new good is always finite.

This paper contributes to the growing literature on measuring the welfare gains from new goods. A classic example is the work by Hausman (1999), who studies the introduction of cellular telephones. He finds that their tardy inclusion in the CPI, some 15 years after their debut, results in a bias of up to 2 percent per year in the telecommunications–services price index. The engine of Hausman's analysis is the consumer's expenditure problem. While this is dual to the consumer's maximization problem, it is hard to recover the utility function from the expenditure function. He also suggests a measure of welfare based on an approximate demand curve. In the PC example studied here this approximate demand curve method leads to a serious underestimate of the welfare gains arising from the introduction of a new product.

Another interesting example is the Goolsbee and Klenow (2006) study of the benefit to consumers of the internet. They estimate the demand for the internet by relating the time spent using the product to the opportunity cost of time. An approach which, they argue, makes sense since internet access is a good whose marginal cost consists almost solely of the leisure time spent by the consumer. They find very large welfare gains, when taking a literal interpretation of the model's structure. This is due to the fact that in their specification the marginal utility of internet consumption approaches infinity as consumption goes to zero. To mitigate the impact of the zero-consumption region of the utility function, they emphasize an alternative measure based upon a linearized leisure demand curve. Additionally, their setup requires the elasticity of substitution to be greater than one. This is satisfied in the data for internet consumption. But, it isn't true for all products. A case in point is cellular telephones, which Hausman estimates to have an elasticity less than one.

Finally, Petrin (2002) considers, as an example, the introduction of the minivan to demonstrate a technique for estimating welfare gains in the absence of consumer-level data. He shows how information describing the purchasing habits of different demographic groups, in conjunction with market-level data, can be used as a suitable substitute for consumer-level data. In his discrete-choice analysis mini-van consumption is a lumpy good, so the specification of the utility function is not central.[1]

2 Computers

Computers first became available in the United States in the 1950s but at prices so high and sizes so large that, for the most part, no individual would want to buy one. It wasn't until the early 1970s,

[1] Greenwood and Uysal (2005) model a world with lumpiness in consumption and many consumer goods. An increase in income, or a fall in price, leads to a shift in consumption along the extensive margin, as the set of goods consumed changes. The full implications of indivisibilities in consumption have not been fully explored in the literature yet.

with the invention of the microprocessor, that the first generation of microcomputers–computers that were small enough to fit on a desk and inexpensive enough to be owned by individuals–was born. Lasting from 1971 to 1976, this period was characterized by a growing interest in computers among engineers and hobbyists. The year 1977 marks the birth of the PC. The key difference between PC's and their microcomputer predecessors is the amount of electronics expertise that the use of the later requires. In other words, PC's are computers that are both small in size and user-friendly to individuals with no technical training.

The first PC to be successfully mass produced was the Apple II. Released in June of 1977 it consisted of a microprocessor running at 1 megahertz, 4 kilobytes of random-access memory (RAM), no hard disk, and an audio cassette interface for program loading and data storage. The computer retailed at approximately $1,200. Systems with larger amounts of RAM were also available up to a maximum of 48 kilobytes and at a price of approximately $2,600. Rapid technological progress led to consistent improvement in the Apple II following its release. For example, in 1978 the floppy disk drive peripheral became available. Far superior to cassettes, the addition of floppy disks greatly improved the quality of Apple II computing.

Since the introduction of the Apple II rapid technological progress in computer development has fueled continual quality improvements and declining costs of production. Compared to the Apple II, today's computers are often equipped with multi-core processors running at over 3,000 megahertz, gigabytes of RAM, and hard drives capable of storing hundreds of gigabytes of data.

Quality improvements in computers and computer production have resulted in an enormous fall in quality-adjusted PC prices. In fact, prices have dropped at an astounding rate of 25 percent per year. Thus, a PC today is more than 700 times cheaper than one in 1977. Starting from virtually zero demand for computers in and preceding 1977, the fall in prices throughout the last thirty years has been synonymous with a rapid rise in demand. Figure 1 presents price and quantity indices for computers and computer peripherals for the period 1977 to 2004.[2] As the demand for

[2] See the Appendix for information on the data.

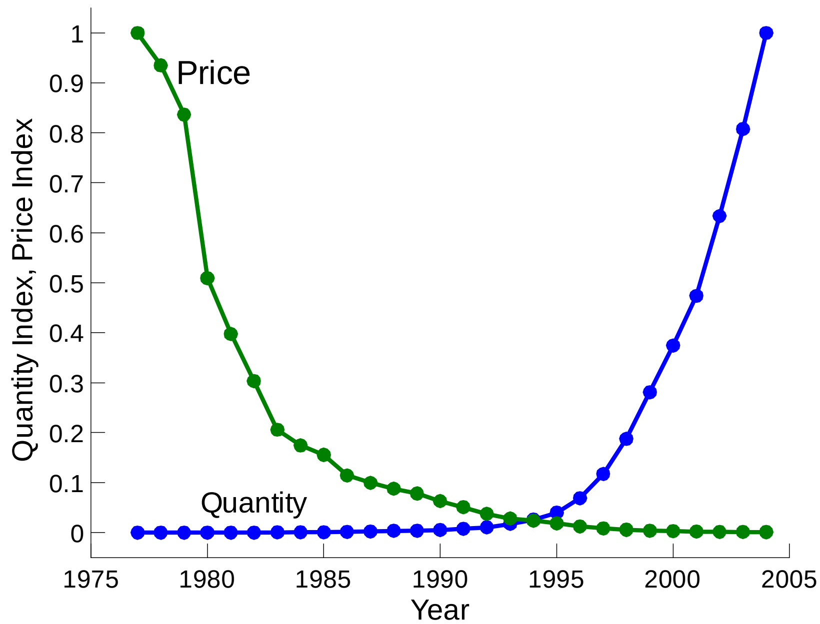

Figure 1: Price and Quantity Indices for Computers, Peripherals and Software for the Years 1977 to 2004

personal computers rose so did their share of total expenditure. Figure 2 shows computer's share of total expenditure since 1977. It rose from zero in 1977 to more than 0.6 percent in 2004.

3 Model

Consider an individual with income, y, that can be used to purchase general consumption goods, c, and computers, n. Computers are measured in some sort of standardized, quality-adjusted units and sell at a price of p in terms of consumption. Let the person's tastes be described by

$$\theta U(c) + (1-\theta)V(n), \text{ with } 0 < \theta < 1. \quad (1)$$

Take the utility function for the consumption of general goods to be of the standard constant-relative-risk-aversion variety, so that $U(c)$ can be written as

$$U(c) = \frac{c^{1-\rho}}{1-\rho}, \text{ with } \rho \geq 0.$$

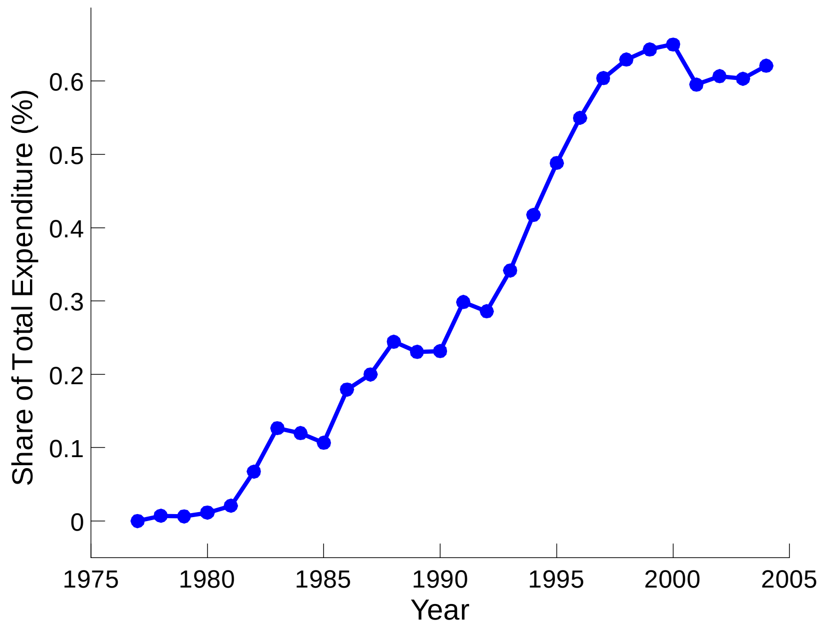

Figure 2: Computers, Peripherals and Software's Share of Total Personal Consumption Expenditure for the Years 1977 to 2004

Notice that $U(c)$ satisfies the standard properties $U_1(c) > 0$, $U_{11}(c) < 0$, $\lim_{c\to\infty} U_1(c) = 0$, and $\lim_{c\to 0} U_1(c) = \infty$. Represent the utility function for personal computers by

$$V(n) = \frac{(n+\nu)^{1-\rho}}{1-\rho}, \quad \text{with } 0 < \nu < \infty.$$

The function $V(n)$ is completely standard except that

$$V(0) = \frac{\nu^{1-\rho}}{1-\rho} > -\infty \text{ and } V_1(0) = \nu^{-\rho}.$$

Observe that since $\rho \geq 0$, the magnitude of the elasticity of demand for computers is unrestricted. The implications of these assumptions on the utility function for personal computers are portrayed in Figure 3, for the case where $\rho \geq 1$. The conventional formulation is illustrated by the dashed line. Note that one could set $V(0) = 0$ by redefining the utility function to be $[(n+\nu)^{1-\rho} - \nu^{1-\rho}]/(1-\rho)$; such a normalization has no implication for the analysis.

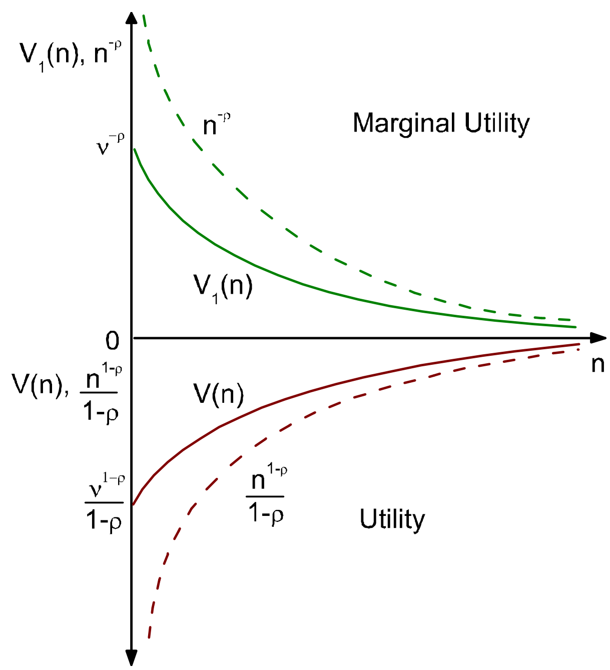

Figure 3: Tastes for Computers when $\rho \geq 1$–Model and Conventional Formulation (dashed line)

The individual's static maximization problem will read

$$W(y,p) = \max_{c,n}[\theta U(c) + (1-\theta)V(n)], \tag{2}$$

subject to his budget constraint

$$c + pn = y, \tag{3}$$

and the non-negativity conditions

$$c, n \geq 0.$$

Note that $W(y,p)$ represents the person's indirect utility function, which gives his maximal level of welfare at the income level y when he faces the price for computers p. The non-negativity constraint on c will never bind and can be safely disregarded, because $\lim_{c\to\infty} U_1(c) = 0$. Since the marginal utility of zero computers is finite, the solution to the individual's maximization problem could be at a corner where $n = 0$.[3]

The solution to the above problem can be obtained by using the budget constraint (3) to substitute out for c in the objective function (2) and then maximizing with respect to n. This leads to the Kuhn-Tucker conditions

$$\theta(y-pn)^{-\rho}p - (1-\theta)\,(n+\nu)^{-\rho} \geq 0,\ n \geq 0, \text{ and } \left[\theta(y-pn)^{-\rho}p - (1-\theta)\,(n+\nu)^{-\rho}\right] n = 0. \tag{4}$$

The equations in (4), in conjunction with the budget constraint (3), determine the demand functions for c and n:

$$c = C(y,p) = \begin{cases} y, & \text{if } p \geq \widehat{P}(y) \equiv \frac{1-\theta}{\theta}\nu^{-\rho}y^{\rho}, \\ \frac{y+p\nu}{1+[(1-\theta)/\theta]^{1/\rho}p^{(\rho-1)/\rho}}, & \text{if } p < \widehat{P}(y), \end{cases} \tag{5}$$

[3] Utility functions of the form $U(c) = (c+\psi)^{1-\rho}/(1-\rho)$ have been used in macroeconomics before. For instance, Chatterjee (1994) and Rebelo (1992) employ such utility functions to model savings behavior. When $\psi < 0$, so that there is a subsistence level of consumption, savings will be small at low levels of income. Kongsamut, Rebelo and Xie (2000) study long-run sectoral reallocations using such a utility function within the context of a multisector growth model. When $\psi < 0$ a good will have an income elasticity less than one. Alternatively, if $\psi > 0$ then the income elasticity is greater than one. In these analyzes when $\psi > 0$ the constraint that $c \geq 0$ is not imposed; it isn't required for the purposes at hand. One could think about $\psi > 0$ as representing some non-market production of the good in question that can be sold (implying $c < 0$) so that only $c+\psi$ needs be non-negative. Note that with this interpretation some positive quantity of the good $c+\psi > 0$ will always consumed. By contrast, the constraint in the current context is necessary. It is what leads to *no* computers being purchased when the price is high enough.

and

$$n = N(y,p) = \begin{cases} 0, & \text{if } p \geq \widehat{P}(y), \\ \frac{y+p\nu}{p+[(1-\theta)/\theta]^{-1/\rho}p^{1/\rho}} - \nu, & \text{if } p < \widehat{P}(y). \end{cases} \quad (6)$$

Observe from (6) that for any given income level, y, there exists a threshold price, $\widehat{P}(y)$, such that the optimal expenditure on computers will be zero whenever $p \geq \widehat{P}(y)$. The threshold price is increasing in income. This implies that along a falling price path the rich will buy the good before the poor do.

Last, suppose that computers can be produced from final output according to the production function $n = zo$, where o is the use of output in computer production and z is the level productivity in the computer sector. Under this assumption the price of computers is simply given by $p = 1/z$.[4] Thus, the decline in the price of computers over time can be identified with exogenous technological progress in the production of computers. It is hard to comprehend how the observed astonishing 25 percent annual price decline can be anything else.

3.1 Welfare Gain

What is the welfare gain to consumers in 2004 from the invention of personal computers and the fall in their relative price since 1977? The welfare gain will be measured in terms of both the equivalent and compensating variations.

First, suppose it is the year 2004 and computers have never been invented. As is readily apparent from (6), this is the same as assuming that computers exist but sell at some prohibitively expensive price, say $p = \infty$. How much more income would you have to give to the consumer so that his welfare level without computers is equivalent to the one he obtained with them? This is the equivalent variation. Let λ_{EV} be the additional income required, measured as a percentage of actual 2004 income, y_{2004}. When computers do not exist the person will spend his entire income

[4] Imagine that final consumption and computers are both produced using capital and labor in line with Cobb-Douglas production technologies. If labor's share is the same in both sectors it then follows that consumption and computers can be effectively transformed between each other using a linear technology of the form postulated above.

on the aggregate market good. His maximal utility will be

$$W((1+\lambda)y_{2004},\infty) = \theta\frac{[(1+\lambda)y_{2004}]^{1-\rho}}{1-\rho} + (1-\theta)\,\frac{\nu^{1-\rho}}{1-\rho}. \tag{7}$$

In the year 2004 the consumer actually did purchase computers at the price p_{2004}. Assuming that he undertook his purchases optimally, his indirect utility function specifies a welfare level of $W(y_{2004}, p_{2004})$.

The equivalent variation is determined by solving the following equation for λ_{EV}:

$$W((1+\lambda_{EV})y_{2004},\infty) = W(y_{2004}, p_{2004}). \tag{8}$$

That is, the equivalent variation, λ_{EV}, renders the individual indifferent between consuming $(1+\lambda)y_{2004}$ of the market good, c, and zero computers, on the one hand, and consuming his actual 2004 consumption bundle when computers exist and are available at 2004 prices, on the other. Using equation (7) in (8) yields

$$\lambda_{EV} = \frac{\left[(1-\rho)\,W(y_{2004}, p_{2004}) - (1-\theta)\,\nu^{1-\rho}\right]^{\frac{1}{1-\rho}}}{\theta^{\frac{1}{1-\rho}}\,y_{2004}} - 1.$$

Notice that the equivalent variation can be computed given data on total expenditures and prices, and estimates of the three preference parameters, ν, θ, and ρ.

The second measure of welfare that will be considered is the compensating variation. The compensating variation is similar to the equivalent variation. In fact, for quasi-linear preferences the two are equivalent. The compensating variation is the amount of income that would have to be taken from the consumer in 2004 to give him the level of welfare that he would have realized if computers had never been invented. Denote the compensating variation, measured as a percentage of the agent's 2004 income level, by λ_{CV}. The compensating variation, λ_{CV}, solves the equation

$$W((1-\lambda_{CV})y_{2004}, p_{2004}) = W(y_{2004},\infty). \tag{9}$$

Although λ_{CV} cannot be written explicitly, it is uniquely defined by equation (9) and can be computed numerically, given estimates of the preference parameters in conjunction with the data on prices and expenditures.[5]

4 Quantitative Experiment

The task is to compute the welfare gain to consumers in 2004 due to the invention of the PC in 1977 and the subsequent decline in its price? In order to compute this, information about appropriate values for the preference parameters must be obtained. There are three preference parameters to pin-down: the coefficient of relative risk aversion, ρ, the weight on utility from aggregate market consumption net of computers, θ, and the parameter ν which is important for specifying the marginal utility of zero computer consumption. These parameters are determined using the following calibration/estimation procedure.

To begin with, for each year t between 1977 and 2004 let $\mathbf{p}_t$ represent the quality-adjusted price of computers relative to aggregate market consumption net of computers, and $\mathbf{y}_t$ denote total expenditure at date t in the data. Similarly, let $\mathbf{n}_t$ be the quantity of quality-adjusted computers purchased from the data. The price and expenditure data is taken from the BEA–see the data appendix for more detail. Given the quality adjustment that the BEA does to the data, think about $\mathbf{n}_t$ as representing the quantity of computers denominated in some sort of standardized unit. Figure 1 shows the PC price and quantity indices. Next, note that given values for the preference parameters the model's prediction for the quantity of computers consumed at some date t, $\widehat{\mathbf{n}}_t$, can by computed by plugging the corresponding price and income levels, $\mathbf{p}_t$ and $\mathbf{y}_t$, into the demand functions specified by (6) to obtain $\widehat{\mathbf{n}}_t = \mathbf{N}(\mathbf{y}_t, \mathbf{p}_t)$. These demand functions also depend on the model's underlying parameters, ρ, θ, and ν. Denote this mapping from the preference parameters to the prediction for the quantity of computers consumed by $\widehat{\mathbf{n}}_t = \mathfrak{N}(\rho, \theta, \nu; \mathbf{y}_t, \mathbf{p}_t)$.

Finally, the preference parameters are determined by minimizing the sum of the squares of the

[5] In particular, note that

$$W((1-\lambda_{CV})y_{2004}, p_{2004}) = \frac{[C((1-\lambda_{CV})y_{2004}, p_{2004})]^{1-\rho}}{1-\rho} + \frac{[N((1-\lambda_{CV})y_{2004}, p_{2004}) + \nu]^{1-\rho}}{1-\rho},$$

where the functions $C(\cdot)$ and $N(\cdot)$ are specified by (5) and (6). Also, recall that $W(y_{2004}, \infty)$ is given by (7).

difference between the quantity of computers purchased as observed in the data and the quantity consumed as predicted by the model over the period 1977 to 2004. This estimation is undertaken subject to a constraint that will be discussed now. The BEA reports that a zero quantity of computers (probably some trivial amount) was consumed in 1977 while they were available at a positive price. Very small amounts are reported in the years immediately after 1977. In order to track accurately the small amounts of computer consumption in the early years a restriction will be imposed on the estimation that predicted purchases of computer in 1977 must be zero. In other words, the parameters are chosen by solving

$$\min_{\rho,\theta,\nu} \sum_{t=1977}^{2004} [\mathbf{n}_t - \mathfrak{N}(\rho, \theta, \nu; \mathbf{y}_t, \mathbf{p}_t)]^2,$$

subject to

$$\mathfrak{N}(\rho, \theta, \nu; \mathbf{y}_{1977}, \mathbf{p}_{1977}) = 0.$$

Essentially, one can think of the constraint as identifying ν.

The calibration/estimation procedure results in a value for ρ of 0.993, a value for θ of 0.994, and one for ν of 6×10^{-4}. The values are reasonable. The value for ρ suggests that the preferences are nearly logarithmic. With logarithmic preferences, at high levels of expenditure the coefficient $1 - \theta$ will represent computer's share of expenditure. In 2004 this was exactly 0.006, so that the share of general goods in spending was 0.994. Last, ν is only 0.06 percent of the quantity of computer purchases in 2004. The model's prediction for the quantity of computers demanded along with the quantity consumed from the data are given in Figure 4. As can be seen, the model fits the data remarkably well. The R^2 is 0.999. The room for an improvement in fit through the use of other functional forms would appear to be small.

Plugging the parameter values and 2004 data into the formulas for the equivalent and compensating variations yields an equivalent variation of 3.94 percent and a compensating variation of 3.77 percent. This compares with Hausman's (1996) estimate of 0.002 percent due to the introduction of Apple-Cinnamon Cheerios, which is a minor product innovation. Petrin (2002) reports a wel-

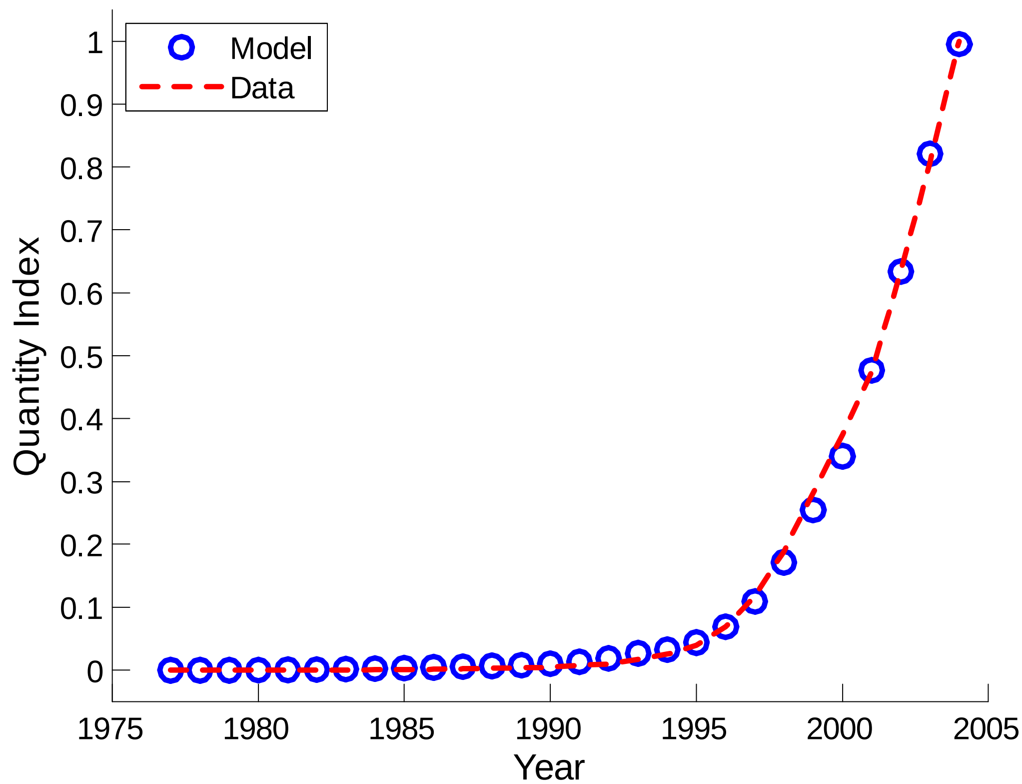

Figure 4: Quantity Indexes for Computers, Peripherals and Software for the Years 1977 to 2004–Data and Model

fare gain of 0.029 percent associated with the advent of the minivan, a more substantive product. A much smaller fraction of the population owns minivans as compared with computers, though. Furthermore, this product has not seen the remarkable price decline that computers have. In a similar vein, Goolsbee and Petrin (2004) find a 0.035 percent gain tied to the genesis of satellite TV. The current estimate is far below Goolsbee and Klenow's (2006) one of 26.8 percent resulting from the internet, at least when the model is interpreted literally. They note that with the isoelastic utility function that they choose "the utility from the first units of consumption is so high" that the welfare gains will be large.[6] As was mentioned, Goolsbee and Klenow (2006) present an alternative, smaller, estimate (their preferred one) based upon a linearized leisure demand curve to reduce the sensitivity of the welfare gain estimate to this region of the utility function.

Hausman's (1999) approximate demand measure of the welfare gain from the introduction of a new good is 0.5×(share of new good in expenditure)/(price elasticity of demand). The time series data for computer consumption suggest a price elasticity of 1.83. Taking their 2004 expenditure share of 0.006 (one of the larger values recorded as can be seen from Figure 2) suggests a welfare gain of only 0.16 percent. This is a far cry from the true value that obtains if tastes take the form specified in (1) with the estimated parameter values. The small number obtained from Hausman's approximation procedure results from the fact that computers constitute a small share of expenditure. Yet, they still are important in generating utility. In fact, Hausman's measure performs worse than a simple Tornqvist index, which suggests that welfare rose by about 2.2 percent–which is still less than 60 percent of the true rise. His linear demand approximation method is likely to perform better for the introduction of more minor products, such as Apple-Cinnamon Cheerios, which can be viewed as a small change from the status quo.

[6] Modelling the consumption of internet services is trickier than other goods, as the paper makes clear. Most consumers purchase internet services at a fixed monthly price. Therefore, they can use as much of the services in a month as they desire. The limiting factor is the amount of time that a individual wants to spend on the internet. This is why Goolsbee and Klenow (2006) estimate the demand for the internet by relating the time spent using the product to the opportunity cost of time, an innovative idea. Modifying the utility function to bound the marginal utility of internet services at zero consumption would lower the welfare estimate. It may also help to explain Goolsbee and Klenow's (2006) fact that 37 percent of people were not on line. Putting more concavity in the utility function at high levels of consumption would help lower the welfare estimate as well.

Thus, a simple model of a representative consumer with a slight modification to the standard isoelastic utility function can lead, using a straightforward calibration/estimation procedure and aggregate data, to a reasonable measure of the welfare gain realized from the introduction of PCs. A few words of caution are in order, however. First, since the parameter values are not determined through a statistical estimation, the analysis is silent on standard errors and other tests of the model. Second, the welfare measures are conditional on the parametric form chosen for utility. This is a problem that many econometric approaches suffer from as well. On the latter point, there may be nonseparabilities between computers and other goods in the utility function. For example, Gloosbee and Klenow (2006) assume that internet services and leisure are Edgeworth-Pareto complements in the utility function. This could be true of computers more generally, of course. Think about playing computer games. Internet services could also be an Edgeworth-Pareto substitute with housework, if they can be used to reduce time spent on chores such as paying bills, shopping, etc. Gloosbee and Klenow (2006) also mention that there may be spillover effects across consumers that are important for household computer adoption. Entering a network externality into tastes may provide another route for modelling the low initial demand for computers. More sophisticated specifications of tastes would probably require more data in order to estimate the structure well, such as the time-use data used by Gloosbee and Klenow (2006).

5 Conclusion

What is your PC worth to you? About 4 percent of total consumption expenditure is the answer obtained here. This finding is predicated upon a simple model of consumer demand. A slight modification of the standard isoelastic variety of preferences results in a well-behaved demand for computers: demand drops to zero as prices rise to some well-defined level, and the consumer's surplus associated with a new good is always bounded. The model of consumer demand is fit to national income and product data, using a straightforward calibration/estimation procedure, to uncover the taste parameters needed for the welfare analysis. The parameter values obtained are reasonable and the framework fits the aggregate data well.

6 Appendix–Data

All data derives from the U.S. National Income and Product Accounts, Tables 2.4.4 and 2.4.5, and spans the period 1977 to 2004. These tables are available on the website for the Bureau of Economic Analysis (BEA). When mapping the model into the U.S. data, the variable n is taken to be real personal consumption expenditure on computers, peripherals, and software. This series is constructed by deflating nominal personal consumption expenditure on computers, peripherals, and software by the price index for this particular series. Note that BEA adjusts these series, through using hedonic price methods and other techniques, for the quality improvement in computers, peripherals, and software that occurs over time. The variable c represents real personal consumption expenditure on all other goods. This is obtained by subtracting nominal personal consumption expenditure on computers, peripherals, and software from total nominal personal consumption expenditure, and then deflating by the price series for personal consumption expenditure. The relative price p is simply taken to be the ratio of the price index for personal consumption expenditure on computers, peripherals, and software to the price index for personal consumption expenditure. Last, real income, y, is simply defined by $y = c + pn$, which is total personal consumption expenditure.

References

Chatterjee, Satyajit. (1994) "Transitional Dynamics and the Distribution of Wealth in a Neoclassical Growth Model." *Journal of Public Economics* 54(1): 97-119.

Goolsbee, Austin and Klenow, Peter J. (2006). "Valuing Consumer Products by the Time Spent Using Them: An Application to the Internet." *American Economic Review*, 96(2): 108-113.

Goolsbee, Austin and Petrin, Amil. (2004). "The Consumer Gains from Direct Broadcast Satellites and the Competition with Cable TV." *Econometrica*, 72(2): 351-381.

Greenwood, Jeremy and Uysal, Gokce. (June 2005). "New Goods and the Transition to a New Economy." *Journal of Economic Growth*, 10(2): 99-134.

Hausman, Jerry. (1996). "Valuation of New Goods Under Perfect and Imperfect Competition," in *The Economics of New Products*, eds., T. Bresnahan and R. Gordon, Chicago: University of Chicago Press, 209-237.

Hausman, Jerry. (1999). "Cellular Telephone, New Products, and the CPI." *Journal of Business and Economic Statistics*, 17(2): 188-194.

Kongsamut, Piyabha; Rebelo, Sergio and Xie, Danyang. (2001). "Beyond Balanced Growth." *The Review of Economic Studies*, 68(4): 869-882.

Petrin, Amil. (2002). "Quantifying the Benefits of New Products: The Case of the Minivan." *Journal of Political Economy*, 110(4): 705-729.

Rebelo, Sergio. (1992). "Growth in Open Economies." *Carnegie-Rochester Conference Series on Public Policy*, 36(July): 5-46.