The Use of Hedonic Regressions to Handle Quality Change: The Experience in the U.S. CPI

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ABSTRACT

A consumer price index (CPI) is a measure of average change over time in the prices of the goods and services that households purchase to satisfy their needs and wants. One of the fundamental problems that the producers of CPIs face is that the characteristics of goods and services, not just their prices, change over time. In this paper we describe the efforts by the US Bureau of Labor Statistics to capture the impact of changing characteristics on measured price change. Hedonic quality adjustment, excluding the case of shelter, is now employed in item categories comprising approximately 2.9 percent of the CPI. The product cateogries currently being evaluated for potential expansion could increase this total by approximately 0.3 percent.

Introduction: Hedonic Quality Adjustment and New Goods

A consumer price index (CPI) is a measure of average change over time in the prices of the goods and services that households purchase to satisfy their needs and wants. One of the fundamental problems that the producers of CPIs face is that the characteristics of goods and services, not just their prices, change over time. If prices were the only aspect of consumer items that changed, producing a CPI that accurately measured price change would be much more straightforward.

The non-price aspects of consumer goods and services, often referred to as "quality characteristics", can change in various ways. We can make some (perhaps not-very-useful) distinctions among them. There are:

- Old consumer items that change—for example, by adding new features or improving performance,
- New consumer items that perform the same function as the old ones but in a better (or at least novel) way, and
- Completely new, never-before-seen, consumer items that satisfy a consumer need or want that has never been satisfied before.

The new items may, fairly soon after their arrival, drive old ones from the marketplace, or the old and new items may coexist. We can lump all these cases together and speak of a single issue for CPIs, which we call the *new goods problem*. That is, the problem of changing product characteristics, or the quality change problem, is fundamentally indistinguishable from the new goods problem.

Just as there are several ways that new goods can appear, there are several ways that ignoring the arrival of new goods may harm a CPI. First, the new goods may add to the product options available to consumers. If there is a "value of variety," there will be

a welfare gain to consumers that is ignored by the index. This issue was raised and analyzed empirically by Hausman (1997) in the case of breakfast cereal.[1]

Second, if the CPI item samples systematically omit new goods and if new goods exhibit price movement that differs from that of the old goods, the movement of the CPI will not represent the movement of the prices of the set of items that consumers are currently buying. While there are arguments that the new goods do exhibit atypical price behavior—entering at a high price and following a "U-shaped cost curve"[2]—this aspect of the new goods problem is an issue more for sampling than for quality adjustment procedures. Nevertheless, we will argue below that the existence of differential price trends within item categories does have implications for the way in which hedonic regression techniques are implemented.

Third, new goods may lead to bias in the CPI if their prices are systematically lower (or higher), on a quality-adjusted basis, than the prices of the old items. Traditional CPI methods, such as "linking," rely on versions of the "Law of One Price," so that the differences in prices between old and new items can be treated as the value to consumers of the differences in quality. Although this assumption is probably a good first approximation in most situations, many economists would argue that it is severely violated in markets undergoing rapid innovation and product turnover. This is where the hedonic regression methods are most obviously useful. The ability to estimate directly and compare the quality-adjusted prices of new and old products offers not only an increase in effective sample size but also a means of capturing the overall benefits of technological improvements in consumer products.

The arrival of new goods also requires the CPI to monitor the consumption of the old item. Because consumers reduce their purchases of the old item as they shift to the new one, a CPI, to be accurate, should reflect this behavior by replacing the old items in its sample with the new ones. To the degree that a CPI is able to put new goods into its samples as replacements for old goods and the degree that we can isolate the price and quality differences between them, the CPI can solve an important part of the new goods problem.

The U.S. CPI has been accused of giving insufficient attention to the new goods problem. Aside from changes necessitated by item disappearance, the regular five-year sample rotation cycle was the only mechanism for systematic introduction of new items. One reason for this may be the legacy of the index's Laspeyres orientation. The objective of a Laspeyres price index is to obtain the current cost of a base period set of consumer items. This sidesteps the need to deal with new products except for the cases where an old good has been driven from the market entirely. A second reason for not dealing more aggressively with new products is more practical. If we replace old products in the CPI samples with new ones, we need to have sound quality adjustment values to make the price comparisons. The motor vehicle strata provide an example where the CPI was

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[1] It should be noted that this issue may only apply if, as in the case of the U.S. CPI, the cost-of-living index is accepted as the fundamental measurement framework.

[2] See, for example, the 1996 "Boskin Commission" report on the CPI (U.S. Senate 1996).

forced to deal with new products. Because vehicle manufacturers traditionally replace models each year, the CPI had to adopt a model changeover procedure for the vehicle item strata. The regular substitutions of new models eventually led the BLS to find a way to estimate the value of the quality differences between models to be able to estimate the pure price changes.

We have identified various ways that new goods can be brought into the CPI. These approaches can be reduced to:

- Adding new items to existing samples
- Redrawing the samples so that they reflect the spending patterns of a more recent period
- Replacing the items in the current samples with new items on a one-to-one basis.

The last way has the advantage of matching each new item to an old one and thereby enabling the CPI to reflect price change between the new and the old item. The difficulty, as noted above, is in estimating the value of the differences between the new and the old item. We treat the difference between the price of new item in the current period and the price of the old item in the previous period as composed of two parts: the true price change and the value of the quality difference between the new and old item. Untangling the true price change from the value of the value of the quality changes is the central challenge of this approach to the new goods problem. Hedonic regressions provide a statistical way to accomplish this.

Background on Hedonic Analysis

The use of hedonic analysis to adjust prices for changes in quality derives from two sources. One source is the early work of Court (1939) and Waugh (1928) that sought to explain the variation in commodity prices by examining their relationship with commodity characteristics. Their techniques did not receive much attention and were not used for many years until Griliches (1961) and Chow (1967).[3] These later works spurred much attention in the potential uses of hedonic techniques. This attention was given further impetus by Lancaster (1966), who provided a consumer theory that was based on product characteristics. In his framework, notions of commodity substitution arising from relative price change were transformed into notions of characteristic substitution induced by relative price change. Rosen (1974) elaborated on this theory by stressing that not only do consumers pay attention to product characteristics but also producers seek to provide products with the characteristics that consumers want. Indeed, this has led to an identification problem in the estimation of the hedonic regressions; a point made in Epple (1987). This focus on the supply and demand for characteristics presumes competitive markets. More recently, attention has been directed to imperfect competition and the associated view that firms seek to introduce new products that occupy vacant spaces in the market product-characteristic space. Such models are considered in Berry, Levinsohn and Pakes (1995) and Goldberg (1995) and they rely on an earlier literature

[3] See Berndt (1991) and Triplett (1986, 1990).

formulating the consumer's problem as a probabilistic choice in the context of random utility.[4]

The problem for index number makers is that having a selected a product to price over time what is to be done when there are changes to the product. One solution, when an item disappears, is to find a "close" substitute and attribute any difference in price to difference in quality.[5] Usually this is too great an adjustment for quality differences. The purpose of using a hedonic approach is to obtain an estimate of the price differential that is attributable to product characteristics or quality. As will be explained below, hedonics was used to reduce the overestimate of the (absolute) value of quality change for many CPI goods—e.g., apparel and televisions.

The use of the hedonic approach relies on some strong assumptions. First, product characteristics must be quantifiable. This can be problematic in cases where quality is inextricably tied to consumer perception. For example, the consumption of some goods provides a perceived enhancement in the status of the consumer. In some cases including brand name as part of the relevant characteristic bundle can capture this characteristic.[6] Second, hedonic techniques assume that the collection of relevant product characteristics does not change. This assumption is fine when product changes are non-drastic; that is, if the product change consists of a change in mix or quantities of characteristics in the relevant bundle. However, when product changes are drastic, that is, new characteristics are introduced, the use of hedonic techniques becomes more problematic. Third, the application of hedonic techniques should distinguish between the demand and supply of characteristics. A common assumption is that the supply curve for characteristics is vertical so that all price change, in a competitive market setting, can be attributed to changes in demand.

There are several ways that hedonics can be used in the context of price indexes. One can estimate the equation and use the coefficients of the characteristics as the attending shadow price. When the quantity of a characteristic changes then the shadow price can be used to estimate the value of the change and this value can be used to adjust the observed price change. Alternatively one can use the hedonic equation estimated in the base period to estimate the price of the product in the comparison period. Any price differential can be attributed to quality change. More specifically, let p_b be the base period price, let the hedonic equation be given by $p = h(x)$ where *x* is the characteristic bundle, let $\hat{p}$ be the estimated price, and let p_c be the observed price in the comparison period. The measure of measure of pure price change, after adjusting for quality change, can be obtained from the following relative

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[4] See, for example, McFadden (1980), and for the implications for index number theory see Feenstra (1995).

[5] Other solutions will be discussed below.

[6] Indeed some manufacturers devote much of their advertising expenditures to the creation of such a perception. This is particularly true for the fashion industry.

$$\frac{\frac{p_c}{p_b}}{\frac{\hat{p}}{p_b}} = \frac{p_c}{\hat{p}}.$$

The numerator measures the observed price change and the denominator measures the quality adjusted price change, yielding the term on the right of the equal sign. As shown in Fixler and Zieschang (1992), it is possible to incorporate the hedonic function into the index. In the case where the index number takes the form of a Törnqvist index, then one can also create a sub-index of characteristics that serves to adjust the commodity price index.

The hedonic function $p = h(x)$ can take several forms with the most common ones being linear, semi-log and log-log. Each has some advantages but it is usually the case that one allows the data to select the form—one can use Box-Cox transformations to determine the proper functional form.

Practices of Other Countries

Several European countries and Japan have embarked on incorporating hedonic analysis into their respective consumer price indexes. The French examination of hedonic techniques, as described in Bascher and Lacroix (1999), was motivated by a recognition that linking and other similar techniques were providing too much uncertainty about the magnitude of price change; hedonic techniques were viewed as providing more reliable estimates of quality change. They go on to describe the French approach, which has focused on the application of hedonic techniques to both durable and non-durable consumer goods. In the case of durables, specifically dishwashers, they found that "brand" was the most important characteristic and re-classified the variable to consist of four gradations according to the brand reputation. Apparel items—women's suits and men's shirts—were also studied, with different quality of results. Kinnunen (1999) describes the work of Statistics Finland in adopting hedonic techniques. The approach is one in which a hedonic regression consisting of observed price (dependent variable) and product characteristics and a time dummy (independent variables) is estimated—this is basically the method of Griliches. The coefficient on the time dummy is used as the measure of quality-adjusted price change. Shiratsuka (1999) shows how the Japanese CPI can benefit from quality adjustments that are made as a result of hedonic estimation. The Griliches technique is also used. Shiratsuka finds that when the hedonic indexes for autos, camcorders, and personal computers are accounted for the overall CPI is lowered by 0.04 percentage points. He concludes with the recommendation that the Japanese CPI incorporate hedonic techniques for quality adjustment to improve its accuracy.

Current Use of Hedonics in the U.S. CPI

Apparel

The first use of the hedonics approach to measure quality change in the U.S. Consumer Price Index was for adjusting clothing item prices in the early 1990s. The impetus for experimenting with this technique was a variation on the new goods phenomena, which has long characterized apparel marketing. The attention to new goods

in most contemporary discussions focuses on technological change and the attending improved quality available to consumers. In the clothing industry, however, the steady stream of new goods derives largely from a re-bundling of existing product characteristics to form new fashions. Though this fashion effect is a more an outcome of a marketing activity than an R&D activity, it still provides consumers with the perception that new goods are available. Accordingly, fashion changes make apparel an example of new goods that perform the same function as old ones but in a novel way.

Studying the use of hedonics was critical for this major group of the CPI in the mid to late 1980s because the clothing indexes during this era were not considered to be an accurate reflection of the price change faced by consumers of these goods. In order to understand the problem faced by BLS economists, one must understand how clothing is marketed in the United States. First of all, much of the fashion aspect of clothing is found in the seasonal items heralding the spring/summer and the fall/winter periods when designers and manufacturers introduce the new season's clothing. The non-seasonal clothing is sold year-round and typically is basic and without the fashion aspects of the seasonal items. The seasonal clothing follows a fairly distinct pattern of price behavior each season. When the clothing is first introduced into stores, the so-called regular price of the clothing is in almost every case the highest that this clothing will sell for during its shelf life. It may go on and off sale several times during the season, then be cleared from the store through the end-of-season clearance sale process. Any remaining merchandise usually is sold off in lots to other retailers, such as off-price and discount stores. Since pure price change for clothing occurs when "new goods" are introduced at the beginning of each season, coincident with (often) minor characteristic changes, it is essential to make price comparisons between the new items and the ones that they replace. Again, once the new goods are in the stores, it is rare to observe any price change for the item other than on-and-off-sale price activity. Hedonic modeling of clothing, however, provides values for the characteristics of the goods and enables us to remove the quality difference from the total difference in the price when comparing the prices of one season's clothing with their replacements the following season.

The early work in the hedonic modeling of apparel items was limited to a few areas in which the indexes were particularly troublesome. (See Armknecht and Weyback 1989) After the research reached the stage where results looked promising, the models at first were used only to change the data collection documents and procedures for selecting replacement items for goods that disappeared. Data collection documents, called checklists, rank the quality characteristics for these goods according to their importance. By separating the characteristics into groups or tiers, we found we could better communicate to the price collectors in the field the characteristics to hold constant when selecting replacements.

Even these early improvements had significant payoff for apparel indexes. Prior to the use of the "tiered" checklists, economists in the national office had been able to compare the prices for about four or five out of every ten replacement apparel goods chosen by the price collectors. By the late 1980s, in those strata where the improved checklists were in use, we were able to compare the prices for seven or eight of every ten substitute items chosen. This had important impacts on the indexes for these goods as well. While we knew the indexes of the past were poor reflections of the actual price

changes realized for these goods, the refined indexes were a much truer representation of price change in the marketplace. Our users in the clothing industry and analysts throughout the country noted the improvements and felt that they could have much more confidence in apparel indexes due to the new methodology.

The initial hedonic models could explain only about half of the price change for the goods. However, as our experience with this technique deepened, we were able to add variables to our checklists and to our models that improved the accuracy of each characteristic and vastly improved the explanatory power of the models as well. With a few more years of refinement, researchers in BLS agreed that the models had improved to the point where the next logical step in the progression could be taken. That is, the shadow prices for the quality characteristics were accurate enough to quality-adjust the data used to compute the CPI for apparel. This step was foreshadowed by several articles by BLS economists (see Georges and Liegey 1988 and Liegey 1990). Using the hedonic values for quality adjustments led to further accuracy in apparel indexes. By the early 1990s, we were able to make direct price comparisons (including those in which prices were adjusted for constant quality) for eight or nine of every ten replacement items chosen for the strata with hedonic models in place (see Liegey 1993). Further studies confirmed the impact on apparel indexes (see Liegey 1994).

As we approach the end of the first decade of using hedonic techniques for apparel items, there are a number of issues which appear to limit the growth of this technique in this major group of the CPI. There are, in fact, a number of models which have been developed over the years which, for a variety of reasons, do not lend themselves to quality adjusting the items they address. Part of this has to do with the nature of certain goods. For example, we have had less success with modeling clothing for children than we have in modeling adult clothing. This may relate in part to the more random nature of style where children's clothing is concerned. Alternatively, there may be more variation in the pricing of children's clothing than in the adult markets, since significantly more advertising dollars go towards building demand for adult fashions than for children's clothing. Or, the difficulties in modeling these goods may have to do with the CPI samples for these items, which are significantly smaller than the samples for adult clothing because of the difference in expenditures for these items. Fortunately, our experiences with most categories of adult clothing continue to be very positive and to improve marginally as we gain more experience with these methods. Certainly the items which have the higher relative importance among the categories of clothing have been the focus of our most intense efforts.

There are certain inherent difficulties in using hedonics for clothing that should be noted along with the successes we have realized there. One continuing difficulty is the problem of specification bias. It is all but impossible to collect certain quality characteristics for clothing in a survey such as the CPI. For example, an important aspect of the quality of a particular garment relates to the quality of the fabric used to construct it. We make every effort to collect the product characteristics that can be easily gleaned in the store, such as the fibers used. But any savvy consumer can attest to the fact that the same fiber blends can yield very different qualities of fabric depending on the weaving machines used, the number of threads per inch of fabric, and the finish used on the fabric. These characteristics cannot be collected in a survey such as ours. We believe we make

every effort to collect proxies for certain of these quality characteristics, such as brand, but these efforts are certainly not perfect. Another problem we face is the changing nature of fashion, wherein a characteristic can be viewed very positively in a particular season, not so highly regarded the next. This leads to problems in stability of the parameter values derived from the models. Our research indicates that the factors remain stable for about 18 to 24 months (see Thompson 1993). This requires that the models be specified anew on a very timely basis. Yet this work has a very high cost in terms of resource allocations for the program.

Another factor that increasingly presents difficulties in accurately estimating the values of the quality characteristics for clothing relates to changes in the marketing patterns for these goods. The clothing industry was once very stable, with the same stores (and types of stores) selling similar merchandise over long periods of time. The industry is now characterized by the entry of many different types of stores selling the very same merchandise. New entrants slice the pie just that much more thinly; thus each player is fighting to maintain the narrow market share it has. This means that prices bounce around significantly more than they once did. It also means that the life cycle for a particular item in a particular outlet is much shorter than it once was. As discounters and off-price stores gained market share in recent years, one of the factors in their success was the much faster turnover of stock. Consumers could find new items available throughout a season, rather than only when the new seasonal lines were introduced at the beginning of the season. This has led to traditional outlets having to mimic these trends in order to retain a share of the market. It also means that, coupled with the saturation of stores selling the same merchandise, more power has gone to consumers who have become increasingly fickle (or smart, depending on your perspective) in their buying habits. Many consumers now wait for items to go on sale before they buy. This trend has meant more difficulties in modeling clothing as well. Operationally, researchers in BLS have used the “regular” prices for clothing items in the hedonic modeling routines. This is to avoid the problems associated with a particular price meaning a different thing depending on when in an item’s life cycle the price was collected. The statistical significance of the characteristic values suffers greatly when the prices used in the modeling work are not limited to regular prices. We would far prefer using transaction prices for a variety of reasons, not the least of which is that this would better mirror the realities of the market place. However, internal research indicates serious problems associated with the estimates of characteristic values using transaction prices (see Shepler 1995). This is a field of research we would like to explore further as resources permit, especially given the rapidly changing marketing patterns for clothing. If we are able to overcome the difficulties in using transaction prices, this could lead to streamlined modeling efforts, thus decreasing the costs and time associated with this work.

Another area ripe for additional work is in pricing items across outlets. In other words, as new forms of outlets appear, and as consumer purchasing patterns shift from one to another, we should have a mechanism to follow these changes in consumer choice. This is clearly an additional path for further research, not just for clothing but for other goods and services as well.

Televisions

Effective with the release of the Consumer Price Index (CPI) for January 1999, the BLS began using hedonic-based quality adjustments for the Television stratum of the CPI. The work on the television regressions was reported in the Moulton, LaFleur and Moses (MLM) paper presented at the 1998 Ottawa Group conference.[7]

Televisions have properties that make them a likely candidate for hedonic analysis. They are a high-tech item that is subject to frequent quality improvement as new television models with new, never-seen-before features enter the market place and render older models obsolete. In addition, televisions constitute an entire CPI item stratum as a well-defined item suitable for hedonic analysis. (The data set used to estimate the MLM model covered most, but not quite all, of the item stratum. The authors excluded some low-end models, like black and white televisions, and also some high-end models) As of December 1998, Televisions constituted 0.201 percent of the weight in the Consumer Price Index for all Urban Consumers (the CPI-U) and 0.240 percent in the Consumer Price Index for Urban Wage Earners and Clerical Workers (the CPI-W). The successful implementation of hedonic quality adjustment made an improvement to a fairly big part of the consumer market basket.

MLM used a semilog model and obtained quality adjustment values for screen size, wide screen, liquid crystal display, projection, surround sound, console, picture-in-picture (one tuner), picture-in-picture (two tuner), number of video inputs, brand group, learning/universal remote, and free delivery. The large and significant coefficient on the brand group variable indicated that brand is important. As noted in previous sections, brand may proxy for unmeasured quality characteristics, such as the quality of the manufacturing, and also may reflect the value some consumers place on brand prestige.

Before using the results in the CPI, BLS re-estimated the models with these same variables using data from late 1998. The specification of the models was not, however, adjusted to account for any new television features that arrived on the scene. In order to continue to use hedonic regression quality adjustments for televisions, BLS will have to respecify the equations to accommodate new variables as well as new data. This may be less effort than the original work required, but it is not insignificant.

Television models leave the market place fairly regularly. MLM noted that each month [check this]in the CPI television sample about 15 percent of the models become permanently unavailable and must be replaced, meaning that a typical television remains in the CPI sample for less than a year. Consequently, allowing the natural substitution process to occur provides a number of opportunities to apply quality adjustments. In the future, it may prove desirable to direct additional substitutions in some cases, in order to keep the television sample as current as possible.

Computers

The Producer Price Index (PPI) is a sister program of the Consumer Price Index in the United States. The CPI and PPI share data and research results when appropriate.

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[7] Moulton, LaFleur, and Moses (1999).

For example, the PPI works with motor vehicle manufacturers to determine the value of new or improved features. The CPI uses these values, modified to include the retail markup, to determine the quality adjustments for automobiles and other consumer vehicles. The PPI program has developed hedonic regressions for various types of computers, including both large-scale computers and desktop personal computers; since December 1990 the PPI has used the values from these regressions to quality-adjust price changes for computers in situations of item substitution.[8] The CPI began using the computer results for desktop computers starting with the index for January 1999. The third BLS price program, the International Price Program (IPP), also uses the PPI's computer regression results.

The regressions for desktop computers include variables reflecting chip type and chip speed, amount of system memory, video memory and hard drive capacity, sound system, modem, monitor type and size, type of operating system software, type of office suite software, business system (LAN ready) and manufacturer group.

After assembling the data and estimating the regressions, a team of analysts from the PPI, CPI and IPP programs review the results and suggest how to improve the regression model. One variable that caused considerable trouble was the one for video memory. When it first became a feature of computers and was added to the regression models, the variable yielded implausibly high coefficient values. After discussion, the team decided to leave it out. In subsequent periods the coefficient settled down and behaved much more reasonably, so video memory is now a part of the regular analysis. The first attempts to include office-suite software that is provided with the computers also yielded unreasonable results. In that case, the team realized that they had to distinguish between the basic software—such as Microsoft Works—and the flagships like Microsoft Office. When they made this distinction they obtained consistent but rather high values for the software; this may reflect the software's value to the computer buyer more than its cost of production. The variable for CD-ROM speed never proved significant so they have dropped it from consideration.

The fact that computers change so rapidly has force the team to go beyond some of the traditional BLS practices for hedonic regressions in order to get results that can be used in our indexes. First, they must find data on new computers, their attributes and their prices very quickly. This precludes use of BLS-collected data. The PPI has adopted a procedure of reviewing advertising in magazines and on the Internet and assembling observations from these sources. Second, the hedonic regressions must be rerun very often. The market for computers is so dynamic that product features and their contributions to the total value of the computer change very frequently, and accurately measuring their current value requires very frequent regression runs with newly assembled data.

Somewhat less often than every three months, but still at least annually, the team must reassess the model they are using, in order to account for additional features. They

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[8] See Holdway (1999).

have found when major changes occur—these are usually associated with the introduction of a new master chip such as the Pentium II—they must undertake a special modeling process to enable them to value the change. They refer to these as "bridge regressions." The analysts pool the data for computers with both the new and old chips and eliminate many of the variables for the other important features to focus the result on the chip difference alone.

Perhaps the most salient point to make is that using hedonic regressions for the computer index has had a dramatic impact on index movement. As reported in Stewart and Reed (1999), the BLS estimates that the annual rate of growth of the CPI index for personal computers and peripheral equipment was reduced by an annual rate of 6.5 percent during the period in 1998 studied. Another important point is that these regressions are a significant burden on the staff. The data must be painstakingly assembled (there were 683 observations in a recent regression) and the work must be repeated at frequent intervals to be useful.

Housing

Hedonic methods are also used within the two major shelter components of the CPI, Rent of Primary Residence and Owners Equivalent Rent. These components together comprise approximately 28 percent of the total CPI weight. They do not, however, present substitution situations parallel to those in other item categories, and the role of hedonic adjustment in shelter is confined to certain types of comparisons.

Unlike the items in other CPI samples, the rental housing units in the CPI housing sample age as they are observed over time. Each month the CPI compares the prices of sample housing units to their prices six months earlier—when those housing units were six months newer. (The CPI adds newly built units to its housing sample in most years, but does not use them in index calculation until it has two successive prices for them.) The primary purpose for the housing regressions is to estimate the effect of the aging of the housing units in the sample as we follow them over time. The U.S. CPI has been adjusting the rents for the effect of aging since January 1988.[9] These regressions use a non-linear form that decomposes the rent with variables for the both age and age squared. In addition, there are interaction variables that we construct as the product of age and physical variables such as the number of rooms in the housing unit. One can derive the effect of aging from the derivative of this regression equation with respect to age.

The equation also provides coefficients that yield estimates for the values of our physical attributes (e.g., number of bedrooms, number of bathrooms, number of other rooms, and presence/type of air conditioning) and BLS uses these values to make quality adjustments in the rare cases when these attributes change. (We also quality adjust for changes in furnishings and services included in the rent, but the values for these adjustments are not based on the hedonic regression.) No adjustments are made for differences in the quality of services provided by different sample housing units as newer units replace older ones in the sample.

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[9] Randolph (1988) and Lane, Randolph, and Berenson (1998),

Planned Expansion of Hedonics in the CPI

Concerns About Quality Change in Other Areas

With the improvements in the Consumer Price Index for apparel outlined earlier in this paper came ideas about furthering this research in other important areas of the CPI. Much of the dissatisfaction with the CPI as a cost of living index relates to the failure to measure the improvements in high-tech products and services that are acquired by consumers. Many believe price indexes for these goods and services might reflect long-term declines as the prices, for example, of ever-improving consumer electronics goods fall. Clothing has certain characteristics that are difficult to specify and collect, such as fashion-oriented variables that change very rapidly, and may have widely divergent values even month–to-month. But these problems shrink in comparison to the overriding difficulty in separating consumer electronics products into a bundle of characteristics. Unlike clothing, consumer electronics markets are driven largely by technological advances. This clearly makes it much more difficult to estimate values for product improvements at the time they are introduced to consumers. This is the challenge BLS faces as we undertake to estimate the characteristic values for the additional items. Yet the potential payoff is substantial.

Hedonic Research Using BLS-collected Data

Beginning in fiscal year 1999, as part of a broad CPI Improvement Initiative, the BLS received funding for special data collection to support the expansion of hedonic quality adjustment. The initiative provides money to collect two pricings of approximately 2500 observations in current CPI outlets.

The particular CPI strata selected for the initial phase of the study were chosen with a few simple criteria in mind:

- A perception that there may be some current inadequate accounting of quality change in the items;
- A belief that useful hedonic models could be developed for at least some subset of the items in the stratum;
- A significant number of price quotes for substitute items targeted for quality adjustment relative to the total number of quotes in the stratum.

Eight items have been selected for collection and analysis in 1999:

1) Telephones, including telephone/answering machine combinations;
2) Video cassette recorders (VCRs);
3) Digital versatile disk (DVD) players;
4) Video Cameras (Camcorders);
5) Refrigerators;
6) Microwave ovens;
7) Washers; and
8) Dryers.

The choice of items for the initial study partly relates to the need to collect data within a limited number of item strata. The products listed above are at varying points in their development stream, some being fairly new and and undergoing very rapid technological improvements (DVD players), others having been on the market for some time (refrigerators and microwave ovens). Telephones are somewhere in between, obviously having been around for a long time, but currently marked by important changes (the digital revolution in home-station portable phones). We hope to learn a great deal not only about these particular products but also about how the success we might expect in the future depends on the variations noted among these product groups.

The 2500 quotes collected in 1999 were distributed among the eight items so as to have at least 450 quotes for each group of items, including the observations in the current CPI sample. Past experience and guidance from other senior researchers suggest this to be a workable set of data to use. Approximately 20 to 50 outlets around the country have been identified as those in which each item stratum is currently priced. BLS economic assistants in the field chose the individual observations according to a set of instructions for each item in order to optimize the variety of items selected for pricing. The timing and procedures for collection of the data was arranged in such a way as to avoid overburdening field personnel yet yielding accurate data in a timely enough fashion to permit the modeling to occur within the budget constraints.

The specification and price data are already being reviewed by the respective commodity analysts with expertise in the particular commodity groups. These economists will add further detail to the specifications submitted by the field. This detail entails the use of secondary source information that may be difficult to collect in the retail outlet, but available through industry sources to which the commodity analysts have access. The hedonic modeling itself will be undertaken by economists with experience using these techniques. Researchers in BLS's Division of Price Index Number Research will review the work prior to its adoption in the CPI. The modeling will provide estimates of the values of the individual characteristics that are bundled together in a particular product. Our concerns, prior to actually building the models, relate largely to the constraints imposed by a static view of these fast-changing markets. More specifically, attention will have to be paid to the stability of the regression coefficients, particularly as the bundles of characteristics change. Again, we look forward to gleaning more insights into the operational problems imposed by these conditions as the project progresses.

BLS economists are also working to determine the product and service mix that will be targeted for data collection in fiscal year 2000. We hope to add several services to the items under study because of the increasing role of services in consumption. How many items can be selected in future years will, of course, be influenced by our experiences with the 1999 sample, including how much attention will have to be given to remodeling items on a regular basis. Our knowledge of apparel commodities suggest that stability of the characteristic values is relatively short-lived, so that we would expect items marked by rapid technological change to have even shorter time frames for stable estimates. In any case, we will need to reevaluate our strategy as we learn more about the results from the products selected for the initial year's work.

Research Using Secondary Data

The hedonics projects described above, which are part of the CPI Improvement Initiative, use price and characteristics data collected directly by the CPI field staff. The advantage of using such data is that we can control what is collected and then combine the collected data with the regular CPI data used in the monthly index. The disadvantage is that the regression results are useful only for a limited period. Further changes in the items under study that occur after the special data collection cannot be modeled. After a period of a few years, at most, we will need new data and new regression results if we are to continue to be able to quality adjust for future new goods.

The success of the PPI's computer hedonic model relies in large part on the use of secondary data. This suggests that we should pursue efforts to build hedonic regression models on such data. For the last year we have been working on a project in parallel with the CPII hedonic project. The parallel project uses purchased point-of-sale data for audio products. This will provide an useful comparison with the CPI hedonics for Video products. Compared to the three main items in the Video stratum, there are 12 items in the Audio stratum[10]; consequently, it would require a great deal of special data collection to amass enough data to produce the hedonics for Audio products.

Comparison of the results from the Audio hedonics to those of the Video, should highlight the tradeoffs between specially collected data and secondary data. The Audio data provide observations by retail channel, (a channel is a category of outlet: department store, mass merchandiser, electronics store, etc.) for each manufacturer and model number. The data have the price (the unit value) and the number of units sold in each one week period, but provide very limited information about the product attributes. This forces us to seek much of the information about the products from other sources, usually from the manufacturers' Internet sites. The vendor charges a fairly high price for this point-of-sale data, so it is more expensive than collecting a sample ourselves. On the other hand, the data come continuously with about a one month lag; this would permit frequent reruns and re-specifications of the regressions.

This leads to the general question, applicable to regressions using either primary or secondary data, of how often the hedonics must be updated. Ideally we would update them every month, of course, but a number of practical considerations will force a much more modest schedule. We should distinguish between a simply rerunning the regressions with more current data and completely redoing the regression model, adding new variables and/or changing the functional form. If we have new data, simply rerunning the regressions and getting more current estimates of the value for the old set of product characteristics is all to the good, but it does not provide values for new product characteristics. Completely redoing a hedonic model can be quite resource-intensive and so likely will have to be done less often. Of course, when new product characteristics appear is exactly when a CPI most needs hedonic quality adjustment values. So to make hedonic regression truly of value to CPIs and "hold the gain" in index quality once one

[10] Video has VCRs, DVD players and Camcorders; Audio has Portable CD players, Table CD players, Portable/Home radios, Portable Tape recorders, Portable Radio Cassette players, Headset stereo, Cassette Decks, Main stereo receivers, Speakers, Rack systems, and Shelf systems.

has decided to use this technique for a particular CPI item, one must be ready to redo the regression models fairly regularly and fairly quickly.

Alternative Uses of Hedonic Parameters

The recent expansion of hedonic methods, in the United States and elsewhere, has called attention to the different ways in which hedonic regression coefficients can be used in the construction of price indexes. In the CPI, hedonic coefficients are used only in substitution situations. When a priced item becomes unavailable, a similar item is selected to replace it and, when possible, a direct quality comparison and price adjustment is made between the two items. This is the hedonic version of the standard "matched model" approach to CPI pricing.

In the empirical econometric literature, by contrast, it is more common to compute the period-to-period index directly from the hedonic regression. This is done either by (i) estimating separate regressions for each period and multiplying the resulting coefficient vectors by a specified set of values of the independent variables, or (ii) estimating a single regression covering all periods and determining the price index from the coefficients on time dummy variables.

Under certain assumptions about market equilibrium, the two approaches might yield identical, or at least similar, results. In many product markets, however, there is evidence that new and old items coexist in the market at sharply different quality-adjusted prices. In that case, the first, matched-model application of hedonic methods may be particularly ineffective in capturing the value to consumers of the new items.

Mick Silver (1998) provides a valuable discussion of these problems in the paper he presented at the 1997 Ottawa Group meeting. For the U.S. CPI, the most revealing empirical demonstration was in the televisions analysis in the aforementioned paper by Moulton, LaFleur, and Moses (1999). When hedonic quality adjustments were confined to item substitutions in a simulated matched-model approach, the resulting index change was only 0.4 percentage point less than the published CPI over a four-year period. By contrast, the direct hedonic approach yielded indexes that were between 4.7 and 7.8 percentage points lower, depending on the precise method employed. As the authors of the paper noted, the difference likely arises from the fact that the direct-hedonic indexes incorporated the quality improvements associated with televisions that entered the CPI through sample rotation. The matched-model index only reflected the improvements from televisions entering through item substitution.

The problem is exacerbated by the fact that CPI substitution procedures work against keeping item samples current. Field agents are instructed to find replacement items that are as similar as possible to the items that have disappeared. The motivation, of course, is to minimize the reliance on explicit or implicit quality adjustments, which are potentially inaccurate. Unfortunately, however, it reduces the extent to which the newest, most improved product models or varieties enter the index through item substitution, and thus also reduces the impact of the hedonic method.

To make full use of hedonic quality adjustment values, it is important to develop CPI procedures that ensure that samples are current, that as new models and versions of items come along they enter the samples, and ideally that they enter the samples in a way

that permits them to be compared with older models. We are testing a method, which we call *directed substitution*, that is designed to do this. The new procedure under consideration requires the replacement of items even when the establishment still sells the old item. Items when they enter the sample will be classified as "High end," 'Mid-range," "Budget," etc. When a given model is no longer in, say, the high end because new models have come along and supplanted it, we will seek a replacement high-end substitute. We are testing this procedure in 1999 in the item stratum for personal computers. Coupled with the computer hedonic regression results, which were described above, this should remove much of the new goods bias from this CPI component.

Conclusion

Not counting shelter, hedonic quality adjustment is now employed in item categories comprising approximately 2.9 percent of the total CPI. The video, audio, and other categories currently being evaluated for potential expansion could increase this total by approximately 0.3 percent. Although hedonic regression may not be successfully introduced in all these categories, the BLS goal is to employ the technique as widely as possible in the area of consumer durables.[11]

Services, of course, represent another significant problem area for quality adjustment in the CPI. Medical care, for example, is often cited as a component that is biased upward due to technological advances and associated unmeasured quality gains. In principle, many services indexes could be improved through the use of hedonic methods. In practice, however, the use of hedonics for services faces significant hurdles of output measurement and data collection. Again, medical care provides an example. The quality of medical care treatments—in terms of increased mobility, enhanced life expectancy, etc.—is often difficult to quantify. Moreover, given the nature of the medical care market, it is impossible to rely on the relative prices of different treatment regimes to estimate hedonic coefficients. Therefore, it is likely that any large extension of hedonic methods into the services components will occur only in the long run.

[11] On November 17, 1999, the BLS announced that beginning in January 2000 hedonic quality adjustment would be extended to audio products and camcorders.

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