Measurement errors and quality-adjustment methodology: Lessons from the Japanese CPI

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Introduction and summary

The Consumer Price Index (CPI) is widely used as a measure of inflation. However, there is a growing consensus that the CPI substantially overstates changes in the true cost of living. Table 1 summarizes recent studies on upward bias in the CPI of major industrial countries; the effect of this upward bias ranges from 0.5 percentage points to 1.1 percentage points per year. In the case of Japan, the effect is estimated at 0.9 percentage points per year. Upward bias in the CPI arises because the current CPI fails to account for the dynamic nature of economic activity, such as changes in consumers' behavior in response to relative price fluctuations between goods, the introduction of new goods, and the disappearance of old goods.

Upward bias in the CPI has a direct implication for monetary policymakers, whose major mandate is to maintain price stability. Although biases in inflation measures do not matter when inflation is high, they do matter when policymakers are considering whether to bring down an already low inflation rate. In this sense, as economies approach price stability, accurate measurement of inflation is especially challenging. The importance of accurate price measurement is apparent in a country like Japan where there is controversy as to whether the country is on the verge of deflation.[1] Without upward bias, the Japanese CPI would have shown even stronger evidence of deflation in recent years.

Moreover, accurate price measures are necessary to interpret economic developments, not only involving inflation but also real output and productivity. If measured inflation is rising more rapidly than actual inflation, measured real economic growth is simultaneously being understated. This implies that real incomes and living standards are rising faster than the published data suggest. In addition, the overstatement of inflation creates an automatic and unintended real increase in social security and other indexed federal benefits and a real cut in indexed individual income taxes each year.[2]

In examining the problems of price measurement, a distinction must be made between the measurement of individual prices and the aggregation of those prices into the overall price index. Aggregation may introduce biases, because the CPI assumes that households purchase the same basket of goods and services over time, although, in reality, they substitute some goods for others as relative prices change and new goods are introduced. However, the problems of aggregation are well understood by economists, and workable solutions are within reach.[3]

The most important remaining problems relate to the measurement of individual prices. Observing and measuring individual prices is quite difficult both conceptually and practically. This is because it is very hard to divide the nominal value of a good into quantity and price on a quality-adjusted basis. As the characteristics of products and services are changing rapidly, it is becoming increasingly difficult to define the unit of output and adjust an item's price for improvements in quality. These problems are pervasive in modern economies. For example, automobiles, refrigerators, TV sets, VCRs, camcorders, personal computers, winter jackets, and sports shoes have all changed in ways that make them surprisingly hard to compare with their counterparts in the past. Indeed, as shown in table 1, quality change/new product bias is identified as the largest source of upward bias in the CPI in major industrial countries.

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TABLE 1

Bias in the Consumer Price Index

	U.S.	Japan	Germany	UK	Canada
Source of measurement error					
Upper level substitution	0.15	0.00	0.10	0.05–0.10	0.10
Lower level substitution	0.25	0.10			
New products/quality change	0.60	0.70	< 0.60	0.20–0.45	0.30
New outlets	0.10	0.10	< 0.10	0.10–0.25	0.07
Total	1.10	0.90	0.75		0.50
Range	0.80–1.60	0.35–2.00	0.50–1.50	0.35–0.80	

Sources: Advisory Commission to Study the Consumer Price Index (1996), Shiratsuka (1999), Hoffmann (1998), Cunningham (1996), and Crawford (1998).

In this article, I investigate the problems inherent to the quality changes/new goods bias in the CPI, taking the Japanese case as an example. I review the sources of measurement errors in the CPI and examine the problems inherent in the methodology used for quality adjustment in the Japanese CPI. I describe the basic framework of the *hedonic approach* (methodology to analyze the price–quality relationship by regressing prices on numerous characteristics of a product) and propose a practical way to improve the accuracy of quality adjustment by introducing this approach to the conventional procedure to compile the CPI. While I use Japan as an example, these measurement problems apply equally to the U.S. or any other industrial economy experiencing rapid technological progress.

Sources of measurement error in the CPI

There are several sources of measurement error in the CPI as a measure of change in the cost of living, such as substitution bias, outlet substitution bias, and new products/quality change bias.

Substitution bias arises because the price index formula fails to reflect consumers' behavior in response to changes in relative prices. For example, beef and chicken are generally thought to be close substitutes. This implies that there will be a shift in household expenditure from beef to chicken when the price of beef increases. Since the weights applied to beef and chicken in the CPI are those of the base period, an upward bias is introduced by the overvaluation of the price increase of beef.

Outlet substitution bias relates to consumers' shift to lower priced outlets, reflecting structural changes in retail markets. In recent years, there has been a transformation of retail, shifting to supermarkets and discount stores. Therefore, it has become increasingly important to keep up with the outlets surveyed so as to record accurately the prices paid by consumers. However, prices surveyed for the CPI do not cover all the consumers' price search activities across outlets located close to each other.

The largest source of measurement error in the CPI, quality changes/new goods bias, stems from the difficulty of adjusting fully for quality change and the delayed introduction of new products. A cost of living index measures the impact of pure price changes relative to a particular reference period, while keeping the utility level or consumers' satisfaction constant. In this context, it is important to make an appropriate comparison of the quality difference between new products and existing ones and to introduce new products to the index in a timely manner. However, quality improvements are hard to detect, not only in products but also in services, such as medical treatments.

Two problems associated with quality-adjustment methodology

The fundamental problem underlying the quality changes/new goods bias is the inappropriate methodology for quality adjustment in the CPI. In the case of Japan, the CPI has two major problems. First, the quality-adjustment method is too limited to detect quality changes in various products and services. This implies that the accuracy of individual price information is not necessarily high. Second, the official CPI does not cover all products and services and, therefore, misses a large portion of the price decline that typically happens in the early stage of the product cycle.

Accuracy of price information

The CPI surveys specific items continuously. When the products surveyed have disappeared from the market or are no longer representative because of structural changes in the economy or the development of technological innovations, it becomes necessary to substitute survey samples (specifications) in line with the transition of product cycles in the market. In such cases, quality differences between new and old specifications are adjusted so that "pure price changes" are reflected in the price index. These adjustments are called specification changes.

The current Japanese CPI mainly adopts the following three methods of specification changes. First, when the change does not involve any difference either in quantity or in quality, the price of the new specification is directly linked to that of the old one (direct comparison method). Second, when there is an apparent qualitative improvement as well as a price increase, the price index is automatically linked by assuming that the price index of both specifications is constant (price link method). Third, when there are no qualitative changes and the difference between the new and old specifications is attributable to the difference in quantity, the prices are linked after adjusting the ratio of the new and old quantities.

As a price index is supposed to represent a price change of a product while keeping its quality constant, its rate of change should be equal to the rate of change in product price minus the rate of a quality change. That is,

$$\Delta(\text{Quality-Adjusted Price Index}) = \Delta(\text{Product Price}) - \Delta(\text{Quality}),$$

where $\Delta(\cdot)$ represents the rate of change in the variable in parentheses. This relationship is useful for explaining the above three methods for quality adjustment in the Japanese CPI.

The direct comparison method assumes a "quality improvement rate equal to zero," making the price index increase rate equal to the nominal price increase rate. The price link method, on the other hand, assumes a "nominal price increase rate equal to the quality improvement rate," thus making the price index increase rate zero. However, neither method is that realistic. In reality, quality changes might not be equivalent to price changes. Thus, quality differences are appropriately adjusted only when quantity has changed without any qualitative changes, that is, when the third method can be applied. As a result, the CPI does not seem to fully account for actual quality changes.

Figure 1 shows the Japanese CPI for automobiles, the prices of which are adjusted for changes in consumption tax rates. The price indexes for domestic compact cars show a mild upward trend from 1990 to 1994, but seem to have been stable since then. This trend, however, is not consistent with the public image of intensifying price competition in the Japanese automobile market and falling automobile prices in recent years. (The only exception is imported compact cars, whose price index fell sharply from 1994 to 1995.) This difference between the CPI trend and the public perception of automobile prices suggests that the CPI is upwardly biased due to a failure in the index's quality-adjustment methodology over time.

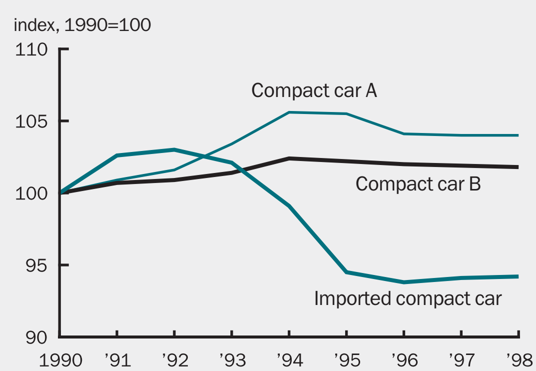
In the U.S., the Bureau of Labor Statistics (BLS), which compiles the CPI, adopts the following three methods: direct comparison, direct quality adjustment, and imputation of price change.[4] The first method, direct comparison, is exactly same as the one in the Japanese CPI. The second one, direct quality adjustment, estimates the quality difference between a discontinued product and a replacement product by using production-cost data or applying *hedonic regression* techniques (I explain the hedonic approach in the next section, beginning on page 6). The third method assumes that the quality-adjusted price of the discontinued product goes up at the same rate as the other items and the excess price difference between old and new products corresponds to the quality difference between the products. Moreover, the BLS employs commodity analysts to examine how to handle substitute items in detail. Therefore, the U.S. procedure seems more rigorous in dealing with quality changes, compared with the ad-hoc methodology applied in the Japanese CPI.

Lagged introduction of new goods and services

New goods and services are not brought into the CPI basket immediately, but with a substantial time

FIGURE 1

Japanese Consumer Price Index, automobiles



Note: Price indexes are adjusted for changes in the consumption tax rates.
Sources: Government of Japan, Management and Coordination Agency, 1990–98, *Consumer Price Index*.

lag after their appearance in the market. This is mainly because the methodology for quality adjustment makes it difficult to construct reliable quality-adjusted price indexes for such products. As a result, the CPI does not thoroughly reflect the impact of the arrival of new goods and services.

When new products are introduced and come into widespread use, households regard new products as relatively less expensive than old products on a quality-adjusted basis. This implies that items included in the CPI survey become relatively more expensive than those excluded from the survey, resulting in an upward bias in the CPI.

Table 2 lists the following products that were newly introduced at the time of base-year revision: compact cars (under 2,000cc engine displacement), pianos, and room air conditioners (1970); fully automatic washing machines, stereos, and tape recorders (1975); microwave ovens and portable calculators (1980); video recorders (1985); word processors and camcorders (1990); and medium-size cars (over 2,000cc engine displacement) and touch-tone telephones (1995).

The aforementioned new products were added to the CPI basket with a certain time lag after they came into widespread use. Figure 2 plots the percentage of households in Japan that own at least one of the itemized list of durable goods. Most durable goods were not introduced in the CPI until more than 15 percent of households owned them. There were especially long lags for stereo phonographs, microwave ovens, word processors, and touch-tone telephones. Moreover, other widely used durable goods, such as personal computers, fax machines, and cellular phones (not shown in figure 2 due to lack of available data) have yet to be included in the survey range.

Lags in introduction are also observed for some services. For example, garage rental charges and amusement park fees are included from the 1985 base, and prices of fast food (such as hamburgers) and video rentals are included from the 1990 base. Telephone bills of the new telecommunication companies and car rental fees are still not included, nor are various financial services, such as credit card fees and account transfer fees.

The lags are especially large for products that are subject to rapid technological innovation and short product cycles. For example, personal computers are not included in the basket for the current 1995-base CPI, although they are known for rapid quality improvements and price declines. The nature of the

TABLE 2

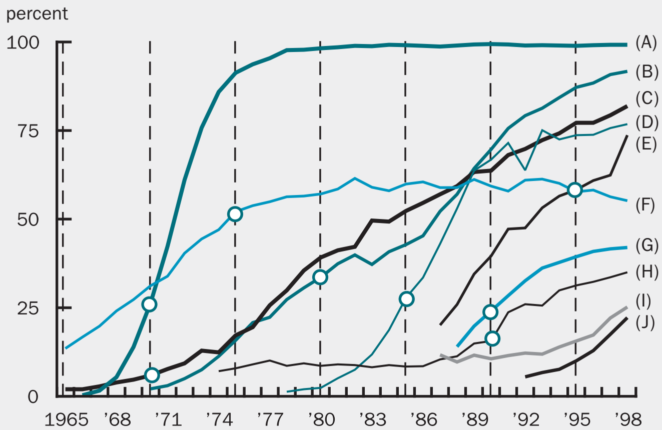
Items introduced in base-year revision

Base year	Durable goods	Services
1970	Automobiles (661cc to 2,000cc engine displacement), pianos, room air conditioners, color TV sets	Driving lesson fees, fire insurance premiums
1975	Washing machines (fully automatic), stereo phonograph sets, tape recorders, gas water heaters	School lunches, expressway tolls
1980	Microwave ovens, portable electronic calculators	Lunch plate for children, women's hairdressing charges
1985	Heaters, video recorders	Garage rental charges, amusement park fees, automotive insurance premiums (optional), sewerage charges
1990	Word processors, camcorders	Hamburgers, video rentals
1995	Automobiles (over 2,000cc engine displacement), touch-tone telephones	Pizzas, karaoke fees
Excluded items	Personal computers and peripherals, faxes, cellular telephones	Telephone bills for new telecommunication companies, rental car fees, financial services, Internet services

Source: Shiratsuka (1999).

FIGURE 2

Diffusion of durable goods in Japan



Notes: The figure plots the percentage of households in Japan that own these durable goods: (A)—Color televisions; (B)—Microwave ovens; (C)—Room air conditioners; (D)—VCRs; (E)—Touch-tone telephones; (F)—Stereo phonographs; (G)—Word processors; (H)—Camcorders; (I)—Personal computers; (J)—Fax machines.

Circles indicate the year in which the products were introduced to the CPI basket. The products without a circle, personal computers and fax machines, are excluded from the CPI basket.

Dashed vertical lines indicate the timing of the base-year revision, which is conducted every five years.

Source: Government of Japan, Economic Planning Agency, 1965–98, *Consumer Behavior Survey.*

personal computer market, which is characterized by a rapid pace of change (relating both to technological innovations and entry and exit of firms), makes it very difficult to construct and update a quality-adjusted price index with the conventional price index methodology. As a result, the decision was made to postpone the introduction of this category of durable goods into the CPI basket until some future date.

In addition, because of the way items are categorized in the CPI, newly adopted commodities are not always compared with existing ones with similar functions in the CPI basket. For example, when personal computers are included in the future, effects that stem from their substitution for word processors will not be taken into account.[5] This implies that the appearance of new goods affects the accuracy of the CPI not only through an improvement in quality but also through an increase in the range of goods and services.

Hedonic approach to estimating quality changes

The hedonic approach to estimating quality changes is based on the assumption that the quality of a product can be measured as an aggregation of the product's objective characteristics. In practice, this approach analyzes the price–quality relationship by regressing prices on explanatory variables that represent important product characteristics (see box 1 for details). The approach originated in Waugh (1928), who applied it to vegetable prices. Court (1939) coined the term hedonic, when he used the approach to capture the characteristics of automobiles that are associated with consumers' "pleasure and comfort."

According to Ohta (1980), the quality of a good has two meanings: first, the objective level of each characteristic that provides utility to consumers and, second, the overall evaluation of such characteristics. To deal with the problem of quality changes in the CPI, I adopt the second meaning, measuring quality in terms of the overall evaluation of objective characteristics of a good, using the hedonic approach.

Empirical application of the hedonic approach takes the form of estimating a regression equation, a *hedonic function*, with observed prices as a dependent variable and performance characteristics as independent explanatory variables.[6] The hedonic function is expressed as:

$$\ln p_{it} = \alpha + \sum_{j=1}^{n} \beta_j x_{ijt} + \sum_{k=1}^{T} \delta_k d_{ikt} + \varepsilon_{it},$$

where p_{it} represents the (natural logarithm of the) price of the ith goods at period t, α is a constant term, β_j is an estimated parameter for the jth characteristics, x_{ijt} is the jth characteristic of the ith good at period t, δ_k is an estimated parameter for the k period dummy, d_{ikt} is a k period dummy variable, and ε_{it} is an error term.

Shiratsuka (1995a, b) and Shiratsuka and Kuroda (1995, 1996) apply the hedonic approach to various products in Japan, such as personal computers, automobiles, camcorders, and apparel, to examine the impact of quality changes on upward bias in the CPI. Based on these studies, Shiratsuka (1999) calculates the effects of upward bias by replacing the CPI item indexes with their estimated hedonic price indexes (see box 2 on page 9 for details of the procedure to compute the price index from the estimated hedonic function). The results are shown in table 3.

When hedonic price indexes for automobiles, camcorders, and personal computers are included, the level of the overall Japanese CPI is lowered by 0.01 percentage points, 0.01 percentage points, and 0.02 percentage points, respectively; the CPI durables index is lowered by 0.16 percentage points, 0.09 percentage points, and 0.36 percentage points, respectively.

BOX 1

Treatment of quality in economic theory

A theoretical foundation for the hedonic approach is based on a new consumer theory known as the Lancaster model.[1] The Lancaster model allows us to address the problem of product quality directly by assuming that the consumer's preference is defined on the characteristic space occupied by amounts of products' characteristics, rather than on the space occupied by amounts of products, which the conventional microeconomic model assumes.[2]

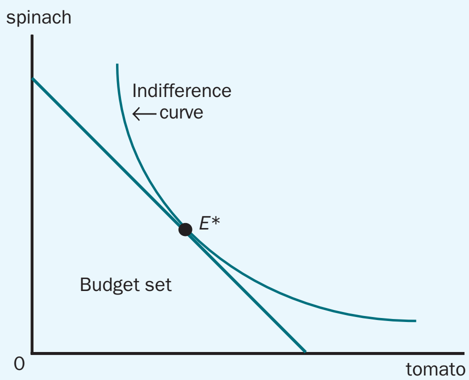
We can use a simple example (in figures A, B, and C), finding the optimal mix of salad ingredients, to illustrate the main difference between the conventional microeconomic model and the Lancaster model. In the conventional microeconomic model, the consumer's preference is defined on the commodity space for spinach and tomatoes. The consumer will choose point E^* in figure A, at which the budget line and an indifference curve are tangent. However, the actual problem for the consumer is different if she cares only about the quantities of vitamins A and C taken from spinach and tomatoes. (In reality, people care about other characteristics, for example, taste and appearance. However, to keep the example simple, I assume the consumer cares only about the two characteristics, vitamin A and vitamin C.) In this case, the Lancaster approach allows us to deal with this problem directly. Figure B decomposes spinach and tomatoes into their contents of vitamins A and C. The angle of the spinach and tomatoes vectors indicates their content ratio of these two vitamins. The length of the two vectors is equal to the amount of spinach and tomatoes that the consumer could purchase if she spent her entire income on that good. In this figure, the consumer will choose point E^{**} to maximize her utility.

What happens when a third, higher-quality good, is introduced? In this context, a "higher-quality" good is one that provides a balanced combination of vitamins A and C at a lower price, like a vitamin pill. Figure C illustrates the impact of the appearance of vitamin pills. The vitamin pills vector is located between the spinach vector and the tomatoes vector, because a vitamin pill contains vitamins A and C in a more balanced proportion. In addition, its vector is longer than the spinach vector or the tomato vector, since, if the consumer spent all of her money on vitamin pills, she would have more vitamins than if she bought only spinach or tomatoes. Clearly, she is better off purchasing vitamin pills instead of spinach and tomatoes (point E^{***}).

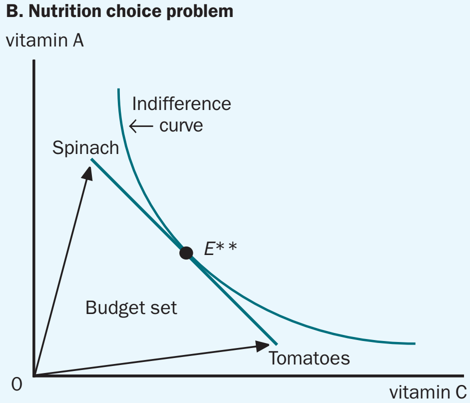
If the conventional microeconomic theory, described in Figure A, is applied, the new vitamin pill is represented as "a third axis," sticking out from the page. The consumer's preference is redefined so as to find the optimal combination of the three goods, spinach, tomatoes, and vitamin pills. However, this treatment is misleading, since the consumer still cares only about the quantities of the two vitamins.

This simple example suggests that the treatment of quality in economic analysis becomes problematic in the modern economy, where quality changes and product differentiation are important phenomena. The Lancaster model provides us with a useful analytical framework to deal with the phenomenon of product diversification and the differentiation of substitutable goods, as well as the emergence of new products.

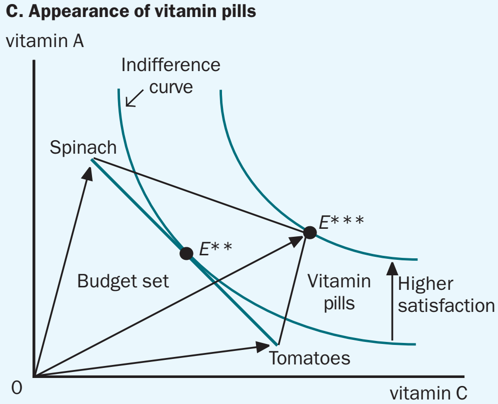
A. Vegetable choice problem



B. Nutrition choice problem



C. Appearance of vitamin pills



[1]See Rosen (1974) for a more detailed discussion of the theoretical foundation of the hedonic approach.

[2]See Lancaster (1991) and Ohta (1980) for the details of the Lancaster model.

TABLE 3

Upward bias in durable goods
(percent)

		Annual change			Contribution	
	Weight	CPI	Hedonic index	Difference	Durables	Overall
Automobiles	1.8	0.1	–0.4	–0.5	–0.16	–0.01
Camcorders	0.1	–4.0	–9.6	–5.6	–0.09	–0.01
Personal computers	0.1	n. a.	–24.4	n. a.	–0.36	–0.02

Notes: The estimates of upward bias are averages from 1991 to 1994. Weights are based on 1990; and half of the weight for word processors in the Consumer Price Index is replaced by personal computers. n.a. indicates not applicable.
Source: Shiratsuka (1999).

Adding these figures gives an upward bias of 0.04 percentage points for the overall index and 0.6 percentage points for the durable goods index. Considering that the relative importance in the CPI basket of these three goods totals just 2 percent, the contribution of durable goods to the overall bias could be substantial if hedonic estimates were obtained for other microelectronic products.

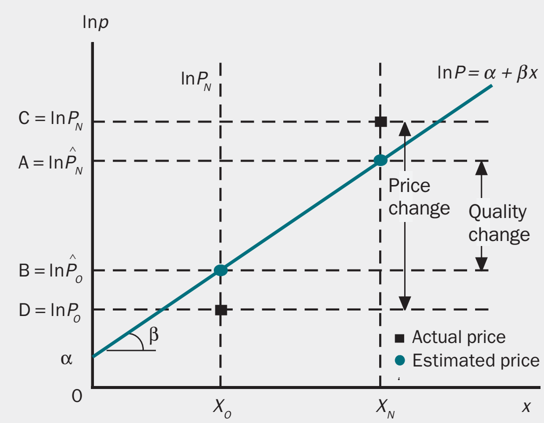
Using the hedonic approach to enhance the conventional methodology

In dealing with the quality-adjustment problems in the CPI, the hedonic approach has an important advantage over the conventional method: It can measure the quality of a product without relying on a subjective judgment of quality. Moreover, once a hedonic function has been estimated, all that is needed to make quality adjustments later is information about the prices and performance characteristics of products. This is particularly useful in constructing a price index for products like personal computers that have short product cycles and experience frequent quality improvements (see box 3 on page 11 for a discussion on the stability of estimated hedonic functions). Next, I describe a practical framework for introducing the hedonic approach into the conventional procedure used to compile the CPI.[7]

This method represents something of a compromise between two requirements. On the one hand, it is necessary to employ the hedonic approach to account for quality changes adequately. On the other hand, it is also necessary to sustain the conventional methodology of surveying specific prices every month. Because of the second requirement, the methodology to calculate a quality-adjusted price index directly from the estimated hedonic functions is not appropriate, although it is most frequently used in empirical analysis with the hedonic approach. Figure 3 illustrates the method for applying the hedonic approach to specification changes for one performance characteristic. The x axis measures the characteristic, and the y axis measures the product price. A straight line with a constant (α) and a slope (β) represents the preestimated hedonic function.[8] Let X_O and X_N represent the characteristic values of the old and new products, respectively. Then the theoretical prices $\hat{P}_o$ for the old product and $\hat{P}_N$ for the new product are the estimated prices based on the hedonic function. The quality change between the old and new products is measured by the difference in the theoretical prices, which is depicted by AB. Let P_O and P_N be the observed prices for the old and new products, respectively. Then, CD measures the change in the product price. Therefore, the difference between CD and AB corresponds to the change in the quality-adjusted price index. In this example, the

FIGURE 3

Application of hedonic approach to specification change



Note: See text for label definitions.

BOX 2

Calculating the hedonic price index

The hedonic price index is a quality-adjusted price index calculated from the estimation results of a hedonic function. The hedonic function I use to calculate the price index is the log linear function as follows:

$$\ln p_{it} = \alpha + \sum_{j=1}^{n} \beta_j \ln x_{ijt} + \sum_{k=1}^{m} \delta_k d_{ikt} + u_{it},$$

where x_{ijt} is the jth characteristic of good i at period t, d_{ikt} is a time dummy for period k, and u_{it} is an error term.

The actual calculation method differs depending on whether it includes an annual dummy in the estimated hedonic function. When an annual dummy is included, the exponentially transformed value of the estimated parameter for the annual dummy becomes the quality-adjusted price index for the full sample and two-year sample estimations. Let x_j* represent the size of the jth characteristic in the base year ($t = 0$). Substituting this into the above equation, then annual dummies at $t = 0$ (base period) all become zero, and for $t = s$ (comparison period) the following holds:

$$d_{ikt} = \begin{cases} 1 & (t = k) \\ 0 & (t \neq k) \end{cases}.$$

Therefore, the estimated quality-adjusted prices for periods 0 and s (… 0) are given by:

$$\ln \hat{p}_0 = \hat{\alpha} + \sum_{j=1}^{n} \hat{\beta} \ln x_j^*,$$

$$\ln \hat{p} = \hat{\alpha} + \sum_{j=1}^{n} \hat{\beta} \ln x_j^* + \hat{\delta}_s,$$

where ^ indicates an estimated value. Taking the difference between these two equations gives:

$$\ln \hat{p}_s - \ln \hat{p}_0 = \delta_s,$$

which implies that the parameter δ_s for the annual dummy is the logarithm of a quality-adjusted price index in period s relative to period 0. Therefore, the hedonic price index $\hat{I}_{0s}$ in period s relative to base period 0 (base period = 100) is obtained as:

$$\hat{I}_{0s} = \exp(\delta_S) \times 100.$$

Next, I consider the one-year estimation, which does not include an annual dummy. Taking the exponential of the value for the size of characteristic x_j*, I obtain the estimated quality-adjusted log-transformed prices as follows:

$$\ln \hat{\hat{p}}_0 = \alpha_0 + \sum_{j=1}^{n} \hat{\hat{\beta}}_{j0} x_j^*,$$

$$\ln \hat{\hat{p}}_s = \alpha_s + \sum_{j=1}^{n} \hat{\hat{\beta}}_{js} x_j^*.$$

Therefore, the hedonic price index for period s relative to the base period 0 is given by:

$$\hat{\hat{I}}_{0s} = \hat{\hat{p}}_s \big/ \hat{\hat{p}}_0 \times 100.$$

quality-adjusted price index rises with an introduction of the new product because $CD > AB$.

With this methodology, the following relationships hold among rates of change in terms of product price, quality, and the quality-adjusted price index.

Δ(Product Price) > Δ(Quality) ==> Δ(Price Index) > zero

Δ(Product Price) = Δ(Quality) ==> Δ(Price Index) = zero

Δ(Product Price) < Δ(Quality) ==> Δ(Price Index) < zero.

Simulation of specification changes

Shiratsuka (1995b) investigates the accuracy of the quality-adjustment method in the CPI through a simulation of specification changes for automobiles, and suggests that quality changes are likely to have caused upward bias in the CPI (see table 4). The study uses preestimated hedonic functions to evaluate the quality changes for 13 Toyota and Nissan models relative to the previous year's models. Table 4 presents the rates of change in product prices, qualities, and quality-adjusted price indexes. Of the 52 simulation samples (13 automobiles for four years), 28 cases have some quality changes. Of these, 27 cases of quality-adjusted change are statistically significant. Eleven cases show an increase in the quality-adjusted

TABLE 4

Simulation for specification changes

Toyota		1991	1992	1993	1994
Corolla	Product price	20.5[a]	0.0	1.4	0.7
	Quality	17.3[a]	0.0	0.0	0.0
	Quality-adjusted price	3.2[a]	0.0	1.4	0.7
Carina	Product price	0.0	–9.5[a]	0.0	9.1[b]
	Quality	0.0	–15.6[a]	0.0	14.3[b]
	Quality-adjusted price	0.0	6.1[a]	0.0	–5.2[b]
Corona	Product price	0.0	8.6[b]	0.0	0.9
	Quality	0.0	18.0[b]	0.0	0.0
	Quality-adjusted price	0.0	–9.5[b]	0.0	0.9
Camry	Product price	0.0	11.9[a]	0.0	–4.0[c]
	Quality	0.0	9.7[a]	0.0	–4.3[c]
	Quality-adjusted price	0.0	2.2[a]	0.0	0.3[c]
Mark II	Product price	0.0	0.0	10.4[b]	2.6[a]
	Quality	0.0	0.0	50.9[b]	–6.2[a]
	Quality-adjusted price	0.0	0.0	–40.5[b]	8.8[a]
Crown	Product price	7.8[b]	0.0	1.8[a]	0.0
	Quality	14.1[b]	0.0	–1.0[a]	0.0
	Quality-adjusted price	–6.3[b]	0.0	2.8[a]	0.0
Celsior	Product price	0.0	5.3	0.2	0.7[b]
	Quality	0.0	0.0	0.0	2.5[b]
	Quality-adjusted price	0.0	5.3	0.2	–1.8[b]
Nissan		**1991**	**1992**	**1993**	**1994**
Sunny	Product price	3.0	2.9	5.9[b]	–4.4[a]
	Quality	0.0	0.0	21.8[b]	–16.5[a]
	Quality-adjusted price	3.0	2.9	–15.9[b]	12.1[a]
Primera	Product price	3.0[b]	4.7[b]	0.8	1.7[b]
	Quality	9.8[b]	9.7[b]	0.0	5.0[b]
	Quality-adjusted price	–6.8[b]	–5.0[b]	0.8	–3.3[b]
Bluebird	Product price	1.3[b]	0.8[a]	1.8	4.1[b]
	Quality	9.2[b]	–8.9[a]	0.0	11.3[b]
	Quality-adjusted price	–7.9[b]	9.7[a]	1.8	–7.1[b]
Skyline	Product price	11.6[a]	0.0	–1.9[b]	14.0[b]
	Quality	9.7[a]	0.0	15.1[b]	23.0[b]
	Quality-adjusted price	1.9[a]	0.0	–17.0[b]	–9.0[b]
Cedric	Product price	13.8[b]	0.0[a]	5.8[b]	0.0
	Quality	27.1[b]	–11.0[a]	12.1[b]	0.0
	Quality-adjusted price	–13.3[b]	11.0[a]	–6.3[b]	0.0
Cima	Product price	0.0[a]	–0.7[a]	9.5[b]	0.0
	Quality	–7.0[a]	–8.7[a]	24.2[b]	0.0
	Quality-adjusted price	7.0[a]	7.9[a]	–14.6[b]	0.0
Inadequate quality adjustment case		7	7	6	7
Increase in quality-adjusted price		3	5	1	2
Decrease in quality-adjusted price		4	2	5	5
Standard errors for hedonic price index		0.7	0.7	0.7	0.7

[a]Indicates increase in quality-adjusted prices.
[b]Indicates decrease in quality-adjusted prices.
[c]Indicates quality difference is insignificant.
Source: Shiratsuka (1995b).

BOX 3

Stability of estimated coefficients in hedonic functions

In examining the feasibility of applying the hedonic approach to the compilation process in the official statistics, one possible concern is the maintenance costs of the hedonic functions used in the quality adjustment. If the coefficients are unstable over time, it is necessary to reestimate the hedonic functions frequently to detect the quality changes appropriately. However, such a requirement might prevent the statistical agencies from adopting the hedonic approach, because it may be judged as impractical given the agencies' resource constraints.

To check this further, I conduct a statistical test on the stability of estimated parameters in the hedonic functions of personal computers and automobiles, based on the estimation results in Shiratsuka (1995a, b). Table A summarizes the results of the F-test on the null hypothesis regarding the common coefficients in all sample periods.[1] The results show that the stability of coefficients in the five-year full sample period is rejected for 1 percent significance in both personal computers and automobiles. However, the null hypothesis regarding stability of coefficients for automobiles in the two-year sample period is not rejected in all the cases, while for personal computers, the null hypothesis is rejected for 1 percent significance in 1991–92, 1992–93, and 1993–94, and for 5 percent significance in 1990–91.

The above results suggest that the stability of estimated parameters for the hedonic functions varies across products and periods. It depends on the fundamental conditions behind the supply and demand for products, such as technological progress and consumers' preferences. It should be noted that it is not necessary to reestimate hedonic functions frequently, say every year, to detect the quality changes appropriately in all the products, and the costs for introducing the hedonic approach could therefore be minimized.

[1]For details of the statistical test of structural change, see, for example, chapter 7 of Greene (1997).

TABLE A

F-test for stability of estimated hedonic function

	Full sample	Two-year sample			
	1990–94	1990–91	1991–92	1992–93	1993–94
Personal computer	10.718	1.586	2.597	4.352	2.193
	0.000	0.038	0.000	0.000	0.000
Automobile	1.565	0.406	0.467	0.500	0.400
	0.000	1.000	1.000	1.000	1.000

Note: Top row in each category indicates f-value; bottom row in each category indicates p-value.
Source: Author's calculations based on estimation results in Shiratsuka (1995a, b).

price index and 16 show a decrease. This implies that the conventional methodology for quality adjustment is likely to produce upward bias in the individual price indexes.

The above simulation uses relatively continuous models to ensure consistency in terms of size and styling of the simulation samples. In practice, however, the construction of a price index faces problems of product diversification, such as changing sizes and styles of automobiles. In such cases, the present construction methodology of the CPI is inadequate and bias is likely to exist. Moreover, because quality changes are not properly taken into account, there is a high possibility that a specification change in the sample structure will be postponed until a future date and miss the best timing.

Conclusion

In this article, I argue that the current methodology in the Japanese CPI fails to account appropriately for quality differences, and suggest that incorporating the hedonic approach into the methodology would improve the accuracy of quality adjustment.

Available evidence suggests that current procedures employed by the statistical agencies are not sufficient to control for quality changes in the economy, not only in Japan but also in other industrial countries. Making improvements in CPI quality adjustment is difficult and requires a significant commitment of resources, since each item needs to be examined separately. Given the importance to policymakers worldwide of creating a better measure of inflation, the introduction of the hedonic approach represents one of the most practical and effective ways to deal with this problem, especially for products experiencing rapid technological advances.

The hedonic approach offers a great advantage over the conventional method: It can measure the quality of a product without relying on a subjective judgment, because it is based on the assumption that quality is determined by a product's performance characteristics. In other words, the quality of a product can be measured as the aggregation of its performance characteristics.

However, the hedonic approach is not perfect, and additional research is needed before the hedonic approach can be applied to quality adjustment for the official CPI. In particular, there is the potential problem of "omitted characteristics," since the approach evaluates quality changes in terms of a specified bundle of performance characteristics. For example, the hedonic approach may create a bias if sizes and styles of automobiles are vastly different. Nevertheless, it should be possible to deal with this problem by estimating a hedonic function with a sample set of similar styles and sizes.

Despite the efforts of many statistical institutions to construct accurate statistics, measurement errors are unavoidable to some extent. Thus, the most important task is to determine whether they are small enough to be safely ignored in practice or serious enough to mislead users. The debate about the accuracy of the CPI should therefore be aimed at investigating the sources of measurement errors and the extent to which they affect accuracy. To date, research on measurement errors in price indexes has been relatively limited in Japan.

NOTES

[1]Shiratsuka (1999) updates the estimation results of upward bias in the Japanese CPI in Shiratsuka (1998). The point estimate remains unchanged, while the upper limit is lowered from 2.35 percentage points per year to 2 percentage points, based on the revised estimation results on the substitution bias.

[2]The most important motivation behind Advisory Commission to Study the Consumer Price Index (1996) was the impact of upward bias in the CPI on the budget deficit.

[3]To deal with the problem of aggregation, it is important to produce an approximation of Törnqvist and Fisher indexes, the "superlative index," which is considered the best proxy for the cost-of-living index, with data available to the statistical agency when they compile the CPI. A possible solution is the application of the CES index formula, proposed by Shapiro and Wilcox (1997). Shiratsuka (1999) suggests that a version of the CES index formula is a good approximation of the superlative indexes in Japan.

[4]For details of quality-adjustment methods applied in the U.S. CPI, see, for example, Armknecht, Lane, and Stewart (1997).

[5]Of course, since many of the new products provide functions that are not available in the old products, there is a limit to exact comparison. Electronic mail and cellular phones are regarded as substitutes for existing telephones, faxes, and postal services, but also have additional features as new means of communication. See Nordhaus (1997) for a detailed discussion of this point.

[6]See Rosen (1974) for a rigorous discussion of the theoretical foundation of the hedonic approach.

[7]In fact, the Japanese Wholesale Price Index, compiled by the Research and Statistics Department at the Bank of Japan, applies this framework to construct price indexes for mainframe computers, personal computers, and some computer-related products.

[8]In this figure, the semi-log linear form, $\ln p = \alpha + \beta x$ is assumed. As shown by Rosen (1974), a hedonic function represents the supply–demand equilibrium of product characteristics in the market. This implies that there is no *a priori* theoretical restrictions on its functional form. Thus, it is appropriate to choose a functional form that is most convenient in practice. In this sense, choice of functional forms depends on 1) estimation fit, 2) theoretical consistency, 3) simplicity of estimation, and 4) ease of interpretation of estimation results. Considering these points, log linear and semi-log linear are very frequently used in the empirical analysis.

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