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The Economic Interpretation of Hedonic Methods

Editor's Note—

This article and the one following are parts of a three-part presentation of the new price index for computers incorporated in the revised estimates of the national income and product accounts (NIPA's) released in December 1985. The new index represents a substantial step in coping statistically with what is referred to as the "quality change problem," a problem common to many products to one degree or another but particularly pronounced for computer equipment because of rapid technological change.

The first article provides an introduction to hedonic methods, the econometrically based approach to dealing with quality change that underlies the new price index for computers. The second article, authored by a group from the economics department of the IBM Corporation, describes the results of their work on developing price indexes for computing equipment. Last year, following circulation of a preliminary description of BEA's research on computer prices, IBM offered to make its research available to BEA and to assist in further development of a computer price index. BEA acknowledges the generous contribution made by the authors and IBM.

The third article, which will appear in a forthcoming issue of the SURVEY, *will describe the use of the IBM composite price indexes in the deflation of current-dollar expenditures for computers in the NIPA's. Corrections to the current-dollar estimates of business purchases of computers that were released in December will appear at the same time. Although work on quantifying the error is not yet complete, it is likely that the corrections will raise the estimates of business purchases of computers, producers' durable equipment, and GNP for 1984 by $4 to $5 billion and the estimates for years back to 1978 by smaller amounts.*

Draft versions of portions of the three-part presentation were read by Zvi Griliches of Harvard University and Joel Popkin of Joel Popkin and Company. BEA and the authors appreciate their comments and suggestions.

CONSTRUCTING price indexes for computer equipment is a challenge because these products have exhibited extremely high rates of quality change, and quality change presents one of the most difficult problems encountered in price index construction. Hedonic methods provide an advantageous alternative to conventional price index approaches for situations where quality change is encountered.

The conventional method for controlling for the effects of quality change is designated the "matched-model" method in this article. In this method, only prices for models, or varieties, that are unchanged in specification between the two periods are used in the index. Matching the models assures that any difference between the prices collected for the two periods reflects solely price change, rather than a change in what was bought. Producer Price Indexes, which are used for deflating many components of producers' durable equipment, are constructed with the matched-model method.[1]

For two reasons, price indexes constructed with the matched-model method may not completely avoid errors that are associated with quality change.

One error arises when the price changes observed for *matched* models do not capture the price movement that is taking place for *all* models. When models embodying an improved technology are introduced, prices of models embodying older technologies are bid down; however, when the older technology cannot successfully compete with the new, it may simply disappear. By following prices of established models until they disappear, the matched-model method misses some of the price change that the new technology engenders, particularly when (as is often the case) the full pattern of discounting is not recorded in the price information used for the index. The potential errors from inferring price change for unmatched models from that observed for matched models, particularly when the matched models become obsolescent, have been discussed in the price index literature for many years.

A second error occurs when models that are not identical are nevertheless matched. Information on some of the specifications of the models, or on aspects of the terms of sale, may not be available, so that some models that appear to be matches actually differ in some respects. Alternatively, the pricing agency may know that two models are not truly identical, but when the differences are small, may conclude that making the match is preferable to dropping the price information from the index. The possibility that unlike models are compared has motivated a good part of the price index literature on quality change. Notice that the stricter the rules for accepting two models as a match, the greater the number of models that will be excluded from the price index. This means that, with the matched-model method, the more one guards against the second error, the more likely the index will contain the first one.[2]

In the BEA price measures for computer equipment, the matched-model method has been supplemented with hedonic methods. Matched-model comparisons are used whenever they are available, and hedonic methods are used to impute missing prices for newly introduced or discontinued models to capture price change that accompanies the turnover of models available in the market. This article introduces hedonic methods and

1. See U.S. Bureau of Labor Statistics, chapter 7, for a description of the methodology for the Producer Price Indexes. (References are at the end of the article.)

2. See Price Statistics Review Committee and Griliches (1971) for a discussion of the quality change problem in economic statistics, and Triplett (1975) for a survey of empirical research.

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shows alternative ways for using hedonic methods in price indexes.

I. The Hedonic Function

The hedonic nomenclature is quite old, going back to the late 1930's.[3] The heart of the methodology is a regression equation, referred to as the "hedonic function," in which prices from an array of different models, or varieties, of a product are the dependent variable and the *characteristics* of that product are the independent, or explanatory, variables.

For example, in the IBM study the hedonic functions for computer equipment took the specific form

$$P = A\, M_1^{b1}\, M_2^{b2}\, u,$$

where P represents the prices of models of a particular kind of computer equipment, M_1 and M_2 are two characteristics of that item of equipment, and u is an error term. The coefficients A, b_1, and b_2 are estimated by the regression, and from the coefficients one can calculate dollar valuations, or implicit prices, for characteristics.[4]

The number of characteristics in a hedonic function, and accordingly the number of implicit characteristics prices, is a technical matter that depends on the product being investigated. The functional form for the regression has usually been determined empirically. The specific form used in the IBM study is one of three alternatives frequently encountered in hedonic studies.

Interpreting the hedonic function

Hedonic methods were developed, and indeed used in price indexes, long before their conceptual framework was understood. At one time, hedonic methods were regarded as ad hoc adjustments, which could not be related to the conceptual basis for economic measurement nor to the theory of price index numbers and real output measurement.

In the last 10 years or so, an explicit conceptual framework for hedonic methods has been developed. The framework is derived from the idea that production or consumption of heterogeneous goods (or services, for that matter) can be analyzed by disaggregating them into more basic, or elemental, units that better measure the dimensions of what is bought and sold—the characteristics. Several examples may help clarify the meaning of the term "characteristic."

Within the computer equipment industry, it is common to refer to a piece of computer equipment as a "box." Although the sale is conventionally denominated in terms of "box" prices and "box" quantities, meaningful economic units, to both buyers and sellers, are the characteristics in the box—speed, capacity, and other measures, as presented in the IBM study. What it costs to build a box, given a technology, depends on the characteristics the builder puts into the box; from the user's perspective as well, what matters is not the box, but the characteristics in it. For an airline company, the transaction unit is a flight, or an individual ticket purchase for a flight; but a better measure of an airline's output is "passenger miles," so passenger miles could be thought of as one characteristic of airline flights. Although a builder sells houses, housing characteristics (such as square feet of floor space, number of rooms, number of bathrooms, and whether the house has a garage or central air-conditioning) are a more meaningful definition of what the builder produces, as well as what the home buyer purchases.

These examples illustrate three principles that define the term "characteristics." Characteristics are homogeneous economic variables that are building blocks from which heterogeneous goods are, figuratively, assembled—the characteristics are "packaged," or "bundled," into a specific model. Characteristics are valued by both buyers and sellers (indeed, one might say this is what makes them economic variables), a key point in the use of characteristics for measurement purposes.[5] Although the characteristics are generally not priced separately, the price for the model represents the valuation of all the characteristics that are bundled in it—for each characteristic, the quantity of it embodied in the model, valued by its "implicit" price.

A simile clarifies, on the one hand, the relation between the price of a model and the prices of the characteristics embodied in it and, on the other, the role of the hedonic function as a "disaggregator."[6] Suppose that grocers, rather than placing their wares on shelves with unit prices marked on them, loaded various assortments of groceries into grocery carts, attaching prices to each of the preloaded carts. Buyers would select a preloaded cart and pay the specified price for the collection of groceries that it contains. Suppose further that a hedonic function were estimated on the grocery cart data. The dependent variable (which in hedonic regressions is normally the price of models of some product, such as automobiles) in this regression consists of the prices charged for the various preloaded carts of groceries. The independent variables (which in the usual hedonic study are measures of characteristics) are here the quantities of various groceries in the available preloaded carts. Thus, groceries found in the carts may be regarded as characteristics of the "grocery bundle." The estimated regression coefficients provide implicit prices for groceries. One can therefore think of the hedonic function as showing what prices of individual groceries would have been, had they been stocked on the shelves in the customary way. Whether on the shelf or in the carts, prices of individual grocery items will be determined by the forces of supply and demand that always determine prices in a market economy.

A heterogeneous good is a bundle of characteristics, similar to those cart loads of groceries. Once the characteristics in the bundle have been identified and measured, the hedonic function is interpreted as a function that disaggregates the price of the good into the implicit prices and the quantities of the characteristics, and it provides estimates of prices for the characteristics. Because the prices

3. See Court for the first use of the hedonic terminology in the literature.

4. In the hedonic literature, the term "implicit price" is often used to designate the coefficients b_1 and b_2 themselves, as well as to denote the price, expressed in dollars.

5. On the buyer side, the idea that demands for heterogeneous goods could be analyzed through demands for the characteristics embodied in them is developed in Lancaster and Ironmonger, though neither noted that the hedonic function might be used to estimate prices for the characteristics. The extension to modeling the supply of heterogeneous goods, explicitly in a hedonic framework, appears in several places, most notably Rosen and in the empirical work of Spady and Friedlaender.

6. The following passage is adapted from Triplett (1976).

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must be estimated, rather than directly observed, they are usually termed "implicit" prices.

Interpreting the implicit prices

Estimated implicit prices for characteristics are the most important empirical results from a hedonic function. Implicit prices have many properties that are similar to those of ordinary prices. As with ordinary prices, an implicit price measures what the seller receives for a characteristic when it is sold as well as what the buyer pays for it. As with ordinary prices, implicit prices for characteristics are proportional to marginal valuations for users, and they are also proportional to marginal costs for producers—but only (as is so well known) when there is competition on the relevant side of the market.[7] The values of implicit prices will reflect the interplay of supply and demand for characteristics, and in the long run competition will push each characteristic price to the cost of producing that characteristic.

Characteristics prices also differ in certain respects from ordinary prices. (1) Because of bundling, the characteristics prices must be estimated with the hedonic function; they can seldom be observed directly, as can ordinary prices. (2) Because the characteristics are purchased as part of a tied sale, in bundled form, relations among the characteristics prices are more complex than what is usually assumed for prices of goods.[8]

Economically meaningful characteristics.—If the characteristics prices estimated from the hedonic function are to be economically meaningful and not just a statistical artifact of a multiple regression, the variables chosen as characteristics must themselves be meaningful. The variables will be meaningful if they represent what a buyer desires in purchasing the product and if they represent what absorbs resources in production.[9] Alternatively, one can say that the variables in the regression are economically meaningful when they represent the inputs used by buyers and the outputs of producers.

Many hedonic studies have departed from the meaningfulness rule, employing variables that are directly interpretable neither as producers' outputs nor as buyers' inputs. For example, early hedonic studies on automobiles employed weight as a variable, even though weight has little to do directly with the usefulness of an automobile or with its production cost.[10] In the automobile studies, weight stood as a proxy for the true characteristics. Use of a proxy variable, however, introduces the possibility of error whenever the relation between the proxy and the true variables changes, and one can never be entirely sure whether such shifts have occurred.

Determining the characteristics of a particular product requires a great deal of technical information, an understanding of what is produced as well as how it is used. It has not always been easy to assemble the technical knowledge. Nevertheless, good design of a hedonic investigation requires that the choice of variables be based on technical considerations about the production and use of the product under investigation.

Resource cost and user value

With hedonic methods, one interprets the variables chosen to represent characteristics both as outputs (which therefore absorb resources) and as inputs (which therefore generate value to the user). What assurance can be obtained that the theoretical interpretation meshes with empirical reality?

Perhaps one can best explore the question by asking: Under what circumstances would either input or output interpretations of characteristics—that is, either resource-cost or user-value interpretations of characteristics prices—be invalid?

A characteristic that represents resource cost, but not user value.—The major cases where a characteristic can only, or primarily, be associated with the cost side of the market involve government regulation. The incorporation of legally mandated smog control devices (as well as analogous noise suppression and safety equipment) would in principle show up in a hedonic function as a characteristic, with a characteristic price (in a competitive situation) approximating its resource cost. In this case, however, the characteristic cannot be interpreted as an input. A smog control device clearly does not provide transportation services.[11] Hence, the device is not an input characteristic when the motor vehicle data are interpreted as investment, or as part of the capital stock, or as consumer durables, even though it is a characteristic of the output of the industries that produce transportation equipment. The implicit characteristic price is interpretable as the resource cost of the output characteristic on the seller side, but as equivalent to a tax on transportation on the buyer side.

A characteristic price can be identified with user valuation, but not resource cost.—Typically, markets are more concentrated on the seller side. If price differentials among models are set by sellers on the basis of their estimates of demand elasticities for characteristics, rather than on the basis of cost, then estimated implicit prices for characteristics will reflect user valuations, but not resource cost.[12]

In this case, unlike the first one, the presumption is that the characteristic itself is both an output and an input. It is only the interpretation of the characteristic *price* that differs from the one presented earlier. Note, however, that the interpretation of the characteristics price under imperfect competition is exactly parallel to standard treatments of goods prices under imperfect competition.

A characteristic price that can be identified with neither user value nor resource cost.—This case is the "false" characteristic, a variable that is correlated with price (and presumably

7. Rosen discusses a competitive equilibrium in which buyers and sellers exchange bundles of characteristics and behave as if characteristics prices represented prices for individual characteristics in the bundle.

8. For example, when the hedonic function is not linear, buyers of different bundles will pay different prices for characteristics, and sellers of different bundles will receive different prices for them, even in competition. See Rosen and Triplett (1976 and 1983, pp. 40–45).

9. This statement may be somewhat too strong in the sense that variables that are related to, or in some way stand for, the true "contents of the box" might also yield acceptable results under some circumstances. See the following paragraph.

10. These studies are listed in the bibliography in Griliches (1971).

11. Some have argued there is a joint product—transportation and clean air—so that the amount of smog control equipment on the vehicle measures its production of clean air.

12. One often hears this conclusion stated backward (and incorrectly): That deviations from competition on the seller side mean that hedonic results do not reflect buyers' marginal valuations.

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therefore with the true characteristics), but from the technical point of view can be identified neither with an output of the producing industry nor with an input of the using industry. As an example of such a variable, the number of ice-cube trays provided with a refrigerator was among the statistically best variables in one analysis of refrigerator prices. The number of ice-cube trays was acting as a statistical proxy for the true characteristics of a refrigerator, with which it happened to be correlated. Obviously, use of estimated implicit prices for ice-cube trays (the estimated implicit price of ice-cube trays was far higher than what they sell for when purchased individually) would yield valid economic measurements for refrigerators only by accident. The use of weight as a variable in automobile hedonic studies provides another example that has already been noted. Such variables typically have been introduced into hedonic functions either because the researcher ignored the principle that variables in the hedonic function should have a technical interpretation, did not understand the technology sufficiently to specify it correctly, or perhaps lacked data on the true characteristics. Such results should, however, be regarded more as errors in the application of hedonic methods than as limitations on the resource-cost or user-value interpretation of hedonic results.

Summary

The interpretation of hedonic functions is generated from the idea that heterogeneous goods are a bundle of characteristics. The price of any model of a heterogeneous good can thus be disaggregated into prices and quantities of characteristics. A hedonic function makes this disaggregation explicit, and provides a set of estimated characteristics prices.

The variables representing characteristics in the hedonic function (if they are properly chosen) and the implicit prices estimated for characteristics are—as are any quantities and prices—economic variables that have interpretations on both sides of the market. The characteristics represent the economic units that are being exchanged in the transaction—that is, they are at the same time outputs for the producer and inputs for the buyer. The implicit prices measure value on both sides of the market, as do any prices.

II. Using Hedonic Methods to Calculate Price Indexes

Key data for constructing quality-adjusted price indexes are the estimated implicit prices for characteristics. There are at least four ways to use the information from a hedonic function to construct a price index.

Making an explicit quality adjustment.—Suppose the classic case of quality change: An "old" model is replaced by a "new" one, the two models differ in the characteristics quantities embodied in them, and a comparison of the prices of the new and the old is needed for a price index. For any characteristic, i, the difference in the quantity of the characteristic embodied in "new" (C_{in}) and "old" (C_{io}) models can be valued by the implicit characteristic price, p_i, to yield the "adjustment": p_i ($C_{in} - C_{io}$).[13] This adjustment can be added to or subtracted from either the price of the new model or the price of the old one, as appropriate, and the adjusted price is then available for use in a conventional price index constructed by the matched-model method. An example of this application of hedonic functions to a component of the Producer Price Index is Triplett and McDonald.

Imputing a "missing" price.—The hedonic function can be used to impute a price in period t for a model that existed in period s, but not in period t. The imputed price permits a synthetic match, so it is then possible to construct a price index with matched-model methods. In the IBM study, such an index is designated the "composite." An early example of the composite index is the computer processor price index produced by Chow; Fisher, Griliches, and Kaysen perform a similar imputation, although for a different purpose. Imputing a missing price and computing an explicit quality adjustment (the first method) are similar in that the hedonic adjustment or imputation is applied only to models that exhibit quality change, while the remainder of the prices gathered for the price index are handled in the conventional matched-model approach.

Calculating a "characteristics price index."—Because the hedonic function provides estimates of the implicit prices of characteristics, it is natural to think of price index numbers that are defined directly on the characteristics and calculated from characteristics prices and quantities. In the grocery cart simile, for example, once one had estimated the prices of groceries on the shelves, a grocery price index could be constructed from shelf prices, rather than from the prices on the preloaded grocery carts. The first construction of a characteristics price index appears in a study by Griliches (1964), who computed Laspeyres and Paasche price indexes for automobile characteristics, as well as the associated characteristics quantity indexes. Characteristics price indexes for four types of computer equipment are presented in the IBM study. The Price Index of New One-Family Houses Sold is constructed as a characteristics price index that estimates the cost, in the current period, of the base period's quantities of housing characteristics (square footage put in place, and so forth), using characteristics prices from the housing hedonic function. This is the only other hedonic price index used for deflation in the national income and product accounts.

Estimating the price index directly from the regression.—Perhaps the most common hedonic price index in the literature is an index estimated directly from a regression: Year, or period, dummy variables are introduced into a regression on two or more periods' data. The resulting regression coefficient is an estimate of the residual (mean) price change between two periods that cannot be associated with changes in the quantities of characteristics. The implicit prices are in effect used to factor out the value of the change in characteristics quantities from the total change in value. The IBM study presents direct regression indexes for four types of computer equipment.

Sometimes the term "hedonic price index" has been thought to imply that the price index must be calculated by the direct regression method.

13. With some forms of the hedonic function, placing a value on the ratio C_{in}/C_{io} is the appropriate calculation.

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However, each of these four calculations provides a hedonic price index in the sense that each uses hedonic methods in the construction of the index. The four calculations are alternatives that have differing practical advantages and usually—but not always—will produce price indexes that show similar patterns of price change.

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