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## Durable goods, price indexes and quality change: an application to automobile prices in Italy, 1988-1998

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# DURABLE GOODS, PRICE INDEXES AND QUALITY CHANGE: AN APPLICATION TO AUTOMOBILE PRICES IN ITALY, 1988-1998

by Gian Maria Tomat*


## Abstract

The paper analyzes the problems of measurement of durable consumer prices posed by quality change. Theoretical price indexes are defined and used to analyze several empirical methods of estimation of quality adjusted price indexes. The paper shows that hedonic regressions and other quality adjustment methods commonly used by statistical agencies do not always provide reliable price estimators. The analysis suggests that the application of methods of measurement based on chain indexes may remove the measurement problems associated with quality change. The paper includes an application of the theory to the analysis of automobile prices in Italy during the period 1988-1998.


JEL classification: C43, C51, D91.
Keywords: durable goods, quality change, hedonic regressions, elementary index numbers.

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## Contents

## 1. Introduction[1]

In recent years there has been an increasing interest in problems of price measurement. In Europe part of the research in this area has been shaped by the process of harmonization of national statistics that began with the monetary union. One of the main concerns of the research on price measurement has been with the question of whether the methods currently used by statistical agencies to compile aggregate price series lead to the compilation of reliable price measures.

Much of the interest regarding the reliability of official price indicators as measures of inflation, followed the release of the research results of the U.S. advisory commission to study the consumer price index (Boskin et. al., 1996). The final version of the "Boskin Report" was presented at the U.S. Senate Finance Committee in 1996. The authors argued that the U.S. CPI was subject to several types of bias and was likely to overstate inflation by around 1.1 percentage points per year.

Subsequent studies performed for other countries tended to confirm the view that the methods that have been used thus far internationally to compile price statistics might have a tendency to generate upwardly biased measures of inflation (see Hoffman, 1998 and Cristadoro and Sabbatini, 1999).

One of the most important problems of measurement that arises in the compilation of aggregate price indicators is the treatment of quality change. The purpose of this paper is to analyze in detail such problem and to provide a critical assessment of the various methods currently adopted by statistical agencies to construct quality adjusted price indexes at the elementary aggregation level. The analysis focuses on the measurement of durable goods prices although many of the considerations related to the problem of quality measurement for the construction of price indexes also apply to the case of non-durable goods.

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The particular problems of measurement that have to be solved when dealing with durable goods are well illustrated in a recent survey by Diewert and Lawrence (2000). In general, they concern the distinction between the *user cost* and the *purchase price* of a durable good. The user cost is usually defined as the price that a consumer would pay over a given time period to hold one unit of the durable good for one period of time; therefore it is also often called the rental equivalent price, although it does not always relate to observable market values.

In conventional terms, the choices on the part of consumers or firms of holding certain amounts of stocks of durable goods, for certain periods of time, are basically determined by their relative user costs. However, for the purposes of economic measurement, the primary interest is to identify methods for aggregating the purchase prices of different varieties of a given durable commodity, so that the resulting price indexes can be used both as indicators of price dynamics and as deflators of nominal durable expenditure.

The problem of measurement is commonly resolved by positing the existence of a no arbitrage condition, which equates the purchase price of a durable good to the flow of rental payments that an economic agent could afford over a given time interval, to obtain a flow of durable good services equivalent to the service flow that would be obtained by purchasing one unit of the durable good at the beginning of the same interval. Such an approach has been exploited previously in studies of durable goods quality change by Cagan (1965) and Hall (1971).

This paper approaches the problem of measurement from a theoretical perspective extending the repackaging model of quality choice developed by Fisher and Shell (1972), Muellbauer (1975) and Gorman (1976) to the analysis of durable consumption and derives the purchase price/user cost relationship in the context of a well defined model of consumption behavior (section 2).

After showing how the extended model can be used to define theoretical price and quantity measures at the elementary aggregation level, the paper turns to the empirical problems of estimating quality adjusted elementary price indexes. The analysis centres around the hedonic regression approach to quality change. Studies using this method to construct quality adjusted price indexes and surveys of literature on the field can be found in

Jorgenson and Landau (1989), Gordon (1990) and Foss, Manser and Young (1993). As known the hedonic approach relies on the possibility of measuring the relevant performance characteristics of a given product. On the basis of the availability of this information the method can be used to study how changes in product quality determined by changes in performance characteristics are reflected in the product price. In turn, this type of analysis is usually used to compute quality adjusted price indexes.

The paper analyzes the problems of specification and estimation of hedonic regression functions and shows that in the absence of a complete information set on the performance characteristics of a product (the general case in actual empirical applications) hedonic regressions can be used to identify and estimate quality adjusted price indexes only if a number of stability conditions on the parameters of the hedonic regressions are satisfied. However, the analysis also shows that it is not possible to test for this assumptions and that therefore it is in general not clear how to construct reliable price measures on the basis of hedonic regressions models (section 3).

The paper then analyzes the methods of quality adjustment that are most commonly used by statistical agencies and shows that similarly to the hedonic approach some of these methods lead to distorted price measures while other methods should provide more reliable quality adjusted price measures. The analysis thus provides some support for the view, shared by most of the empirical literature in the field, that official indexes published by statistical agencies may be subject to a quality change bias. The interpretation given in the paper is that existing quality adjustment procedures allow for too much subjective judgement when evaluating quality change. The analysis suggests that the implementation of methods of measurement that dispense the statistical agency from making quality evaluations, and in particular methods based on chain indexes, may remove most of the quality adjustment problems from price statistics (section 4).

In order to analyze how hedonic regressions and other quality adjustment methods work in practice the concluding sections of the paper present the results of an empirical analysis of price and quality change in the Italian automobile sector for the period 1988-1998. Estimates of hedonic regression functions using price and characteristics of cars sold in the Italian market are provided and the corresponding hedonic price indexes are calculated. These indexes are then compared with alternative price indexes compiled using the same database on the basis of a chain index methodology. The analysis confirms the view that hedonic indexes are not as precise as it would be desirable, although the discrepancies between hedonic indexes and the alternative chain indexes appear to be relatively small on average.

The paper also compares the hedonic indexes and the quality adjusted price indexes compiled using the chain index method with a quality adjusted price index compiled by a private research institution, the Research Center Promotor. The latter index has been calculated using a database similar to the one used in the present paper and shows a tendency to overstate the actual rate of price change. This result can explained by the quality adjusted method used to construct the index.

Finally, the paper compares the above mentioned quality adjusted price indexes with the official automobile consumer price index calculated by the Italian National Institute of Statistics (Istat). In the period considered and taking the chain index as the benchmark, the official automobile CPI shows an average upward bias of 2.2 percentage points per year (sections 5 and 6).

## 2. The theoretical framework

In order to approach the problem of quality measurement we use the repackaging model developed in the seventies by Fisher and Shell (1972), Muellbauer (1975) and Gorman (1976). We provide an extension of the model, to the analysis of durable consumption. In order to capture the temporal dependence which characterizes consumers' choices to purchase durable goods, we use the neoclassical stock adjustment model formalized in contributions by Diewert (1974), Mankiw (1982) and Hayashi (1985). We find that the resulting framework provides a tractable way to deal with the problems of temporal dependence that arise when considering durable quality choice. Moreover, we will show that the model provides interesting insights into the problem of evaluating alternative methods of constructing quality adjusted price indexes.

*2.1 The model*

To introduce the basic elements of the model, suppose that the representative consumer in the durable goods market has an infinite horizon of time with preferences over consumption sequences of a given durable good defined by the utility function:

$$U = \sum_{t=0}^{\infty} v\left(\sum_{i=1}^{n} s_{it}\right)(1+\rho)^{-t} \tag{2.1}$$

where $\rho \geq 0$ denotes the preference discount factor, $s_{it}$ denotes the service flow from the i-th variety of the durable good held in stock by the consumer in period t and there are n varieties of the durable good in the market.

The different durable varieties are assumed to be perfect substitutes for the consumer, thus in each period the stock of each variety enters additively into the utility function through the term:

$$S_t = \sum_{i=1}^{n} s_{it} \tag{2.2}$$

As just defined, the variable $S_t$ represents the index of aggregate durable consumption. We assume that the single period utility function, v, is continuously differentiable, strictly increasing and strictly concave with respect to $S_t$ and that it satisfies the Inada condition $\lim_{S_t \to 0} v'(S_t) = +\infty$.

The above assumptions make the consumer's problem well defined. We focus on the analysis of a model involving choice over a single durable good to keep notation simple; note, however, that the consumer's problem can easily be extended to include choice over many goods, as in Hayashi (1985).

Now assume that durable goods stocks are not defined in terms of physical units but in terms of the service flow that each variety of the durable good provides to the consumer in each period. In particular, denoting with $d_{it}$ the physical quantity of purchases of durable variety i in period t and with $\theta_{it}$ its quality level, we assume that the accumulation equations linking purchases to stocks take the form:

$$s_{it} = \theta_{it} d_{it} + (1-\delta) s_{it-1} \qquad i = 1, \ldots, n \tag{2.3}$$

The quality of each variety of the durable good in the market evolves over time according to the quality parameter $\theta_{it}$, we take the evolution of these quality parameters to be given exogenously. Equation (2.3) also assumes that all durable varieties depreciate over time at a constant rate, $\delta$.

To complete the model we assume that the consumer finances lifetime consumption out of labour income and financial wealth and that there is a single financial asset that can be used to transfer wealth between periods of time. Denote $w_t$ the labour income in period t, $A_t$ the nominal value of financial assets held by the consumer in period t, i the nominal interest rate, which is assumed to be constant over time, $p_t=(p_{1t},\dots,p_{nt})$ the $n\times1$ vector of durable purchase prices in period t and $d_t=(d_{1t},\dots,d_{nt})$ the $n\times1$ vector of durable purchases in period t. The consumer's dynamic budget constraint can then be written as follows:

$$A_{t+1} = A_t(1+i) + w_t - p_t d_t \tag{2.4}$$

We assume that financial markets are perfect, so that the consumer can borrow or lend any amount of money in each period of time at the given interest rate. However, to rule out unlimited borrowing, we impose the standard solvency condition:

$$\lim_{t\to+\infty} A_t(1+i)^{-t} = 0 \tag{2.5}$$

In order to analyze the structure of the consumer's problem it is necessary to provide a formal definition of the user cost of the durable good. In the present context, the user cost of variety i is defined as:

$$r_{it} = \frac{p_{it}}{\theta_{it}} - \frac{(1-\delta)}{(1+i)}\frac{p_{it+1}}{\theta_{it+1}} \tag{2.6}$$

To interpret this definition, note first that the quantity $p_{it}/\theta_{it}$ defines a quality adjusted price, since it represents the expenditure required to buy one additional unit of durable services, purchasing variety i in period t. Thus, at period t market prices, the consumer can buy each unit of his desired stock of variety i at the price $p_{it}/\theta_{it}$. At the beginning of period t+1, only (1-$\delta$) units of the good remain, and they can be sold with a rebate equal to $p_{it+1}/\theta_{it+1}(1-\delta)$. Equation (2.6) therefore defines the user cost of variety i in period t as the present value of the cost of holding one unit of durable variety i in period t in terms of the financial values of period t.

Given the above definition, it is possible to substitute the accumulation equations (2.3) in the dynamic budget constraint (2.4) and solve the resulting difference equation by forward recursive substitutions to derive the consumer's intertemporal budget constraint:

(2.7) $$\frac{1}{1+i}\sum_{t=0}^{\infty}\frac{r_t s_t}{(1+i)^t}=\frac{p_0}{\theta_0}(1-\delta)s_{-1}+A_0+\frac{1}{(1+i)}\sum_{t=0}^{\infty}\frac{w_t}{(1+i)^t}$$

In equation (2.7) $s_t=(s_{1t},\ldots,s_{nt})$ is the n×1 vector of period t durable stocks and $r_t=(r_{1t},\ldots,r_{nt})$ is the corresponding n×1 vector of period t user costs. The equation states that the present value of lifetime expenditure must be equal to the present value of his lifetime wealth. Durable goods' expenditure is expressed here in terms of the stocks held by the consumer in each period of time rather than by purchases. Accordingly, the imputed prices for each stock variable take the form of a rental equivalent price. The intertemporal budget constraint, however, fully incorporates the dynamic stock adjustment process that characterizes the consumer's problem.

The user cost equation (2.6) can also be used to derive a relation between the quality adjusted price of variety i in period t and the stream of its current and future user costs. Solving (2.6) by forward recursive substitutions yields:

(2.8) $$\frac{p_{it}}{\theta_{it}}=\sum_{\tau=0}^{\infty}r_{it+\tau}\left(\frac{1-\delta}{1+i}\right)^{\tau}$$

This equation is essentially a no arbitrage condition in that it states that the quality adjusted purchase price of variety i in period t must be equal to the present discounted value of its current and future rental equivalent prices. According to (2.8) the consumer cannot make gains or losses by trading used durable goods stocks for new ones in the durable goods market. Note that in defining the model, for simplicity, the existence of a rental market was assumed away; however, the model can be extended to include such a market, in which case (2.8) also states that the consumer must be indifferent between purchasing a given amount of stock of each variety i in period t, and renting equivalent amounts of stock from period t onwards.

To show that the consumer's problem is actually well defined, it is necessary to specify the dynamics of the exogenous state variables. We assume in particular that prices of durable varieties, the quality parameters and nominal income take finite values in each period of time and are characterized by constant growth rates.

Denote with $\xi_i$, $\varphi_i$ and $\gamma$ the growth rates of the purchase price of variety i, the growth rate of the quality level of variety i and the growth rate of nominal income, respectively, and note that the definitions just given imply that the growth rate of the quality adjusted price of variety i can be defined as $\pi_i=(1+\xi_i)/(1+\varphi_i)-1$. For equation (2.8) to be consistent with the assumption that quality adjusted prices take finite values in each time period, the growth rate of the rental equivalent price of each durable variety must be smaller than $(1+i)/(1-\delta)-1$. This growth rate is equal to the growth rate of the quality adjusted price of variety i and we thus assume $\pi_i<(1+i)/(1-\delta)-1$.

Moreover, we assume that the growth rate of nominal income is smaller than the nominal interest rate, $\gamma<i$; by making the consumer's lifetime wealth finite this assumption makes the consumer's problem bounded and hence ensures the existence of a solution to the problem.

### *2.2 Optimal plan and implied price dynamics*

In its general form, the solution to the consumer's problem can be found considering that the additively separable structure of consumer's preferences implies that the consumer's problem admits a two stage budgeting representation.

In rental equivalent terms, given an allocation of lifetime wealth between different periods of time, the consumer allocates single period expenditure by choosing the combination of durable varieties that yields the maximum level of single period utility for the given level of expenditure. This allocation problem defines unit cost functions:

$$c(r_t) = \min_{r_{it}}(r_{1t},\ldots,r_{nt}) \tag{2.9}$$

The optimal allocation of lifetime wealth is then achieved by choosing the optimal level of aggregate durable stock to be held in each period, given that each unit of aggregate stock can be valued in each period using the cost function (2.9).

We are interested in the conditions that characterize an internal solution to the consumer's problem, because we want to model a situation in which many varieties of the durable good are traded in the market place in each period of time. The form of the unit cost function defined in equation (2.9) implies that in each period of time only the varieties of the durable good with the smallest user cost will be held in stock by the consumer. It follows that an internal optimal is achieved only provided rental equivalent prices are constant across varieties in each time period:

(2.10) $$r_{it} = R_t \quad \forall i = 1,...,n \ \ \forall t$$

Given the no arbitrage condition (2.8), this in turn implies that a necessary condition for an internal optimal is that quality adjusted prices be equal across varieties in each time period:

(2.11) $$\frac{p_{it}}{\theta_{it}} = P_t \ \ \forall i = 1,...n \ \ \forall t$$

When (2.11) is satisfied, all quality adjusted prices will grow at the same rate $\pi<(1+i)/(1-\delta)-1$. In the next subsection we show how this equation can be used to define theoretical quality adjusted price indexes and quantity indexes.

## *2.3 Measuring real durable consumption and the aggregate price level*

It is relatively easy to see how the model developed above can be used to define theoretical quality adjusted price measures which can be used both as indicators of pure price change in the durable industry and to recover the corresponding theoretical measures of aggregate durable consumption expenditure.

Denoting with $E_t$ nominal durable consumption expenditure in period t, by definition we have $E_t = p_t d_t = \overline{p}_t \overline{d}_t$ where $\overline{p}_t = (p_{1t}/\theta_{1t},...,p_{nt}/\theta_{nt})$ is the n×1 vector of quality adjusted prices and $\overline{d}_t = (\theta_{1t}d_{1t},...,\theta_{nt}d_{nt})$ is the corresponding n×1 vector of quality adjusted quantities purchased in period t. At an internal optimal plan, quality adjusted prices are equal across varieties, it follows that:

(2.12) $$E_t = P_t D_t$$

where the aggregate price index $P_t$ is defined by equation (2.11) and:

(2.13) $$D_t = \sum_{i=1}^{n} \theta_{it} d_{it}$$

Equation (2.12) decomposes nominal durable consumption expenditure into the product of a price index $P_t$ and a quantity index $D_t$. The interpretation of this decomposition can be given by considering that, from the point of view of consumers, durable expenditure is aimed at adjusting the durable goods stock to its desired level in each period of time. In period t, each unit of additional stock can be obtained at the price $P_t$ independently of which variety of the durable good is purchased and so this quantity naturally represents the aggregate price level.

The aggregate stock variable $S_t$ was defined earlier in (2.2) and it is relatively easy to see that the accumulation equations (2.3) imply that the aggregate durable stock in period t can be expressed as:

(2.14) $$S_t = D_t + (1-\delta)S_{t-1}$$

Hence, the series of aggregate purchases $D_t$ obtained from the decomposition (2.11), can be used together with equation (2.14) to obtain the aggregate durable stock series from any given initial condition. This clarifies the interpretation of $D_t$ as the theoretical indicator of aggregate real expenditure.

It is interesting to note that the aggregation problem is resolved in the present context in a manner that is very similar to the solution to this problem given in Muellbauer (1975) for the non-durable goods case. The possibility of defining aggregate quality adjusted price and quantity indexes depends on the equality of the quality adjusted prices of different varieties of a durable good. The extension of the model to capture the intertemporal aspects of consumer’s choice that arise in the durable goods context shows that the key condition generating this equality is a no arbitrage condition, which allows to relate durable goods purchase prices to their rental equivalent costs. The analysis shows that this relationship can be derived from the structure of the consumer's optimization problem[2].

## 3. Hedonic regression functions and hedonic price indexes

The possibility of defining an empirical counterpart to the theoretical price indexes defined in the previous section depends on the possibility of measuring the quality level of different varieties of the durable good under analysis. This problem can be approached by letting the quality level of any given variety be a function of a number of product performance characteristics, some of which are supposed to be observable. Letting $z_{it}=(z_{1it},\ldots,z_{mit})$ denote the $m\times1$ vector of characteristics of variety i in period t, the quality level can be defined as $\theta_{it}=\theta_t(z_{it})$. There are then several ways to proceed, in this section we analyze some aspects of the problem of specification and estimation of hedonic regression functions and hedonic price indexes.

### *3.1 Hedonic regression functions: problems of specification*

The theory provides a justification for making an assumption that quality adjusted prices are constant across varieties in each time period. In order to specify the econometric model we suppose that the price quality relation holds in its logarithmic form in a stochastic environment.

Consider in particular a situation where observations on prices and characteristics of N varieties of a given good over T periods of time is available and denote the sample as $(p_{it},z_{it})$ for i=1,…N and t=1,…T . We make at the outset the simplifying assumption that the random vectors $(p_{it},z_{it})$ are stochastically independent both across individual units and over time and assume that the price mechanism can be described by a conventional regression model:

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2 The problem of quality measurement is often approached using different theoretical frameworks. The most celebrated model used in this field is the household production model, developed in the sixties by Becker (1965) and Lancaster (1966). Early students of price and quality measurement, such as Griliches (1971), often relied on this model to provide a theoretical background for the hedonic regression approach to quality change. More recently, empirical researchers have often made reference to the implicit markets model which was originally introduced in the literature by Rosen (1974) and further developed by Triplett (1983, 1987) and

(3.1) $$\log p_{it} = \alpha_t + f_t(z_{it}) + u_{it}$$

where $\alpha_t$ denotes the logarithm of the quality adjusted price in period t, which is common across varieties, $f_t(z_{it})$ is specified in accordance with the theory developed above and $u_{it}$ is a random disturbance term such that:

(3.2) $$E(u_{it} \mid z_{it}) = 0$$

(3.3) $$E(u_{it}^2 \mid z_{it}) = \sigma_{it}'^{2}$$

The model given in equations (3.1) to (3.3) is a general specification which can easily be related to most of the empirical literature on hedonic regressions. We would like to use the model to estimate a series of quality adjusted price indexes. In (3.1) the series of the logarithm of quality adjusted prices is represented by the parameter $\alpha_t$. As will shortly be clarified, however, it is in general not possible to estimate this parameter in actual empirical applications; therefore we define as the parameter of interest the quantity $\phi_t=\alpha_t-\alpha_{t-1}$, which represents a first order approximation to the pure inflation rate between period t-1 and period t. We look for conditions that would enable us to estimate $\phi_t$.

Clearly, as defined in equations (3.1) to (3.3), the model is not operational. There are three problems that need to be analyzed to make it operational in any particular application: (i) the definition of the relevant characteristics variables; (ii) the definition of the functional form of the regression function; and (iii) the definition of the distributional properties of the conditional process log $p_{it}|z_{it}$ or, equivalently, of the conditional process $u_{it}|z_{it}$.

The first problem arises because we cannot possibly think of being able to define in a quantifiable manner, let alone measure, all the relevant performance characteristics of a given product. These may depend partly on technological factors but also, for example, on consumer tastes which are in general difficult to observe. As a result, the analysis invariably has to be performed with a limited information set. To proceed, it is therefore necessary to partition the vector of characteristics $z_{it}$ into a vector of observable characteristics and a

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Epple (1987). An analysis of the relationships between these models and the repackaging model is provided by Deaton and Muellbauer (1980).

vector of unobservable characteristics and then look for the conditions that must be satisfied to validate the marginalization of the model with respect to the unobservable variables.

Thus, let $z^o_{it}=(z_{1it},\ldots,z_{kit})$ denote the vector of the k observable characteristics and $z^u_{it}=(z_{k+1it},\ldots,z_{mit})$ denote the vector of the m-k unobservable characteristics so that $z_{it}=(z^o_{it},z^u_{it})$. To marginalize the model with respect to the vector of unobservable characteristics, it is necessary to take the conditional expectation of actual prices with respect to the observable performance variables. We suppose that taking this conditional expectation leads to the following reduced model:

(3.4) $$\log p_{it} = \gamma_t + g_t(z^o_{it}) + v_{it}$$

where:

(3.5) $$\gamma_t = \alpha_t + \eta_t$$

and:

(3.6) $$E(v_{it} \mid z^o_{it}) = 0$$

(3.7) $$E(v^2_{it} \mid z^o_{it}) = \sigma_{it}$$

The transformation involved in going from model (3.1)-(3.3) to the latter model involves making the assumption that $E\left(f_t(z_{it}) \mid z^o_{it}\right) = \eta_t + g_t(z^o_{it})$, where $g_t$ is a new function possibly different from $f_t$, and defining the error term as $v_{it} = \log p_{it} - E(\log p_{it} \mid z^o_{it})$. Note that the independent sample assumption implies that $v_{it}$ is white noise and therefore:

(3.8) $$E(v_{it} \mid v_{js}) = 0 \quad i \neq j \ \vee \ t \neq s$$

After this step of reduction, the quality adjusted price parameters $\alpha_t$ are no longer identifiable. In the reduced model given by equations (3.4) to (3.8) only the parameters $\gamma_t$ can be identified. Given inferences on $\gamma_t$, it would be possible to learn about $\alpha_t$ only on the basis of information on $\eta_t$. However inferences on $\eta_t$ cannot be made on the basis of the reduced model and therefore it is not possible to make inferences on the quality adjusted price levels. In turn, the presence of nuisance parameters implies that the parameters of interest $\phi_t$ cannot be identified by differencing $\gamma_t$, since $\gamma_t$-$\gamma_{t-1}$=$\phi_t$+($\eta_t$-$\eta_{t-1}$). We will return to this problem when discussing hedonic price indexes.

Abstracting for the moment from the problem of identification, the second question that needs to be considered regards the form of the function $g_t$ in (3.4). In practice this function is unknown, since the theory does not suggest any particular functional form and, moreover, it is obtained after transformation from the original model. One possible solution to this problem is to parameterize the form of $g_t$ in a flexible way. Suppose for example that:

(3.9) $$g_t(z_{it}) = \sum_{j=1}^{k} B_{jit}(z^o_{jit}, \lambda_j)$$

and that the functions $B_{jit}$ take the Box-Cox form:

(3.10) $$B_{jit}(z^o_{jit}) = \begin{cases} \beta_{jit} \dfrac{{z^o_{jit}}^{\lambda_j} - 1}{\lambda_j} & \lambda_j \neq 0 \\ \beta_{jit} \log z^0_{jit} & \lambda_j = 0 \end{cases}$$

Under additional distributional assumptions, the model defined by (3.4)-(3.10) can be estimated using maximum likelihood methods. It is also possible however to make more specific functional form assumptions. Note for example that equation (3.10) yields, as special cases, the log-log model ($\lambda_j$=0 all j) and the semi-log model ($\lambda_j$=1 all j). Both these models have been widely used in hedonic regression studies because they can be estimated by least squares.

The third question that needs to be analyzed in order to complete the definition of the empirical econometric model concerns the distributional assumptions that have to be made on the conditional process log $p_{it}|z^o_{it}$. In general, the transformations of the independent variables are carried out with the aim of inducing normality of the conditional process. Even granting this assumption, however, an important question for estimation and hypothesis testing regards the form of the variance of log $p_{it}|z^o_{it}$.

In equation (3.7) we did not make any specific assumption about the conditional variance leaving open the possibility that it may vary over cross-sectional units and periods of time and we did not specify the source of the variation. The conditional variance $\sigma_{it}^2$ may simply differ for different sampling units or its variability may depend on other unmodeled parameters. Alternatively, the conditional process may be characterized by heteroskedasticity so that the conditional variance depends on the conditioning variables:

$$E(v_{it}^2 \mid z_{it}^o) = \sigma(z_{it}^o)^2$$

The final possibility is that the conditional variance is constant:

$$E(v_{it}^2 \mid z_{it}^o) = \sigma^2$$

Equations (3.4)-(3.10) plus, if necessary, the normality assumption, provide a preliminary but complete characterization of the empirical hedonic model which can be used for estimation purposes.

### *3.2 Hedonic price indexes: problems of estimation*

From the above considerations, it follows that the possibility of using hedonic regressions for estimating quality adjusted price indexes, depends in general on the results of the reduction from the postulated general econometric model represented by equations (3.1)-(3.3) to the empirical model represented by (3.4)-(3.10). Given the latter model there are several ways that are typically used to compile hedonic price indexes and it is interesting to evaluate these alternatives in light of the preceding discussion.

One method of estimation consists of using the time intercepts $\gamma_t$ and estimating the quality adjusted rates of price change by taking the period by period differences of these coefficients. This method of estimation is usually referred to as the "dummy variable method".

From the above analysis it follows that in general this method of estimation does not allow to identify the actual quality adjusted rate of price change because the marginalization of the general model with respect to the unobservable characteristic variables introduces nuisance parameters on the hedonic regression function. In particular:

(3.11) $$\gamma_t - \gamma_{t-1} = \phi_t + (\eta_t - \eta_{t-1})$$

Therefore, in order to get rid of the nuisance parameters, $\eta_t$, it is necessary to assume that they are constant over adjacent time periods:

(3.12) $$\eta_t = \eta_{t-1}$$

When using the dummy variable method, condition (3.12) is a necessary and sufficient condition for valid marginalization with respect to the unobservable characteristic variables. The drawback of this result is that it is not possible to test the hypothesis of the structural stability of the nuisance parameters in actual empirical applications.

A second method of estimation consists of taking the sample average of the observable characteristics in a given base period and estimating the quality adjusted rate of price change using all the information contained in the hedonic regression function. Denoting this sample average as $\bar{z}_b$, according to this method hedonic indexes are calculated as:

(3.13) $$\gamma_t + g_t(\bar{z}_b) - \gamma_{t-1} - g_{t-1}(\bar{z}_b) = \phi_t - (\eta_t - \eta_{t-1}) + g_t(\bar{z}_b) - g_{t-1}(\bar{z}_b)$$

There are two natural choices for the base period, period t-1 and period t; in the former case equation (3.13) defines what is usually referred to as a “Laspeyres hedonic index”, in the latter case (3.13) defines what is usually referred to as a “Paasche hedonic index”.

In the presence of structural stability of the function $g_t$, (3.13) is equal to (3.11) and therefore does not actually define a new index, however the two estimators differ when the function $g_t$ is unstable. In this latter case, in order for $\phi_t$ to be identified by (3.13) it is necessary that:

(3.14) $$(\eta_t - \eta_{t-1}) + (g_t(\bar{z}_b) - g_{t-1}(\bar{z}_b)) = 0$$

This condition is less likely to occur than condition (3.12), since more nuisance terms are involved.

In the empirical analysis that follows, the hedonic regression model is estimated both on cross section data year by year and as a sequence of adjacent year regressions for overlapping consecutive pairs of years. This choice is justified in light of the structural instability of the regression function used to relate prices to characteristic variables. However, the above considerations highlight some problems that may arise when using hedonic regressions to estimate quality adjusted price indexes; the assumptions behind the model that have been used in the analysis imply that the hedonic regression method in general leads to distorted measures of the rate of price change. The analysis also shows that estimating hedonic indexes using the dummy variable method is in general preferable since the estimators in this case contain fewer nuisance terms; however the precision of hedonic price indexes compiled in this way ultimately depends on the stability of the nuisance parameters $\eta_t$ which in general cannot be tested.

## 4. Alternative quality adjustment methods

The hedonic regression method is not the only method that can be used to account for quality change and statistical agencies most commonly use different aggregation methods to compile quality adjusted price indexes. When discussing these methods it is useful to distinguish between the case where price series are compiled using fixed base indexes and the case where they are compiled on the basis of chain indexes.

In the context of fixed base methods, the bundle of goods on which prices are collected and processed on a regular basis is usually revised at regular intervals, once every five or ten years. To illustrate the problems of measurement that arise in this case, suppose that for a given elementary component of the reference bundle, the statistical agency samples n varieties of a given product and computes a price index for the product using an elementary index number formula; for expositional purposes suppose that this is formula is given by the geometric mean index. Denoting with $p_{i0}$ and $p_{it}$ respectively, the price of variety i in the base period and in the comparison period, the price index is thus defined as:

(4.1) $$P_t = \prod_{i=1}^{n} \left( \frac{p_{it}}{p_{i0}} \right)^{\frac{1}{n}}$$

In terms of the framework developed in previous sections, equation (4.1) should give a good estimate of the price level in period t, because the price estimate is based on a sample of products whose quality levels are given, thus $p_{it}/p_{i0}=(p_{it}/\theta_i)/(p_{i0}/\theta_i)$ where $\theta_i$ is the quality level of the sampled variety i.

For many products, however, the pace of replacement of old qualities by new ones is typically faster than the pace at which bundles are revised. When new products appear on the market replacing old ones, the statistical agency faces the problem of evaluating how much of the price difference between the new versions of the product and the old ones is attributable to quality change and how much to pure price inflation. Moulton and Moses (1997) describe the methods that can be used to perform this decomposition and compile quality adjusted price indexes. We review these methods assuming that at time t variety j has to be replaced. The following alternative quality adjustment methods are available:

*(a) Comparable items/class mean imputation:* In this case the new version of the product is supposed to be of the same quality as the old one so that no quality adjustment is made. Denoting with $p^2_{jt}$ the price of the new version of variety j in period t and with $p^1_{j0}$ the price of the old version of the product in the base period, the individual price index for variety j is calculated as $p^2_{jt}/p^1_{j0}$. An elementary price index is then computed by aggregating the individual indexes of all varieties entering the reference market basket with an appropriate index number formula such as (4.1). A variant of this method occurs when more then one variety replaces an old one but the underlying calculations remain basically the same.

*(b) Overlap method:* In this case it is supposed that the new version of the product may be of a different quality and that price quotations for both the new version and the old one are available during an overlap period, say t-1. The individual price index for variety j is then obtained by chaining the price change of the old version occurring between the base period and the overlap period and the price change of the new version occurring between the overlap period and period t: $(p^1_{jt-1}/p^1_{j0})(p^2_{jt}/p^2_{jt-1})$. An aggregate price index is then computed as above.

*(c) Link method/deletion:* This method is used when it is assumed that the new version of the product is of a different quality from the old one but price quotations for both the new and the old versions are not available during an overlap period so that the overlap method cannot be used. The aggregate price index is then computed by removing the item from the market basket and calculating the index for the remaining items with an appropriate index number formula.

*(d) Direct quality adjustment:* In this case the statistical agency attempts to perform the quality adjustment using additional sources of data, such as information provided by manufacturers on the costs of the quality improvements of a given product.

It is not difficult to show that methods (a) and (d) are likely to generate distorted measures of the rate of price change, while methods (b) and (c) should lead to more reliable estimates.

With regard to methods (a) and (d), consider that the comparison between the new and the old varieties is in general made on the basis of a limited set of characteristics that are thought to represent product quality; just as in the case of the hedonic regression method this is likely to introduce distortions. In particular, two versions of a good may be considered to be of the same quality while they are not because some relevant characteristic variable has not been taken into account; in this case the price ratio $p^2_{jt}/p^1_{j0}$ is different from the quality adjusted price ratio $(p^2_{jt}/\theta_j^2)/(p^1_{j0}/\theta_j^1)$ and the application of method (a) leads to distorted estimates of the rate of price change. In the case of method (d) the statistical agency believes that a quality change has occurred and attempts to obtain an estimate of what the price of the new version of the replaced variety would be in the absence of any quality improvement in order to remove from the computations price variations that arise as a consequence of quality change. The quality adjustments introduced with this method are however still based on a limited information set and therefore are likely to reflect actual quality changes only partially.

To show that methods (b) and (c) should give good quality adjusted price estimates in terms of the economic model developed above, it is possible to use the same line of reasoning as that applied to (4.1) in the absence of sample replacements. In the case of method (b), consider that the rate of price change for the j-th variety is computed as $(p^1_{jt-1}/p^1_{j0})(p^2_{jt}/p^2_{jt-1})=((p^1_{jt-1}/\theta_j^1)/(p^1_{j0}/\theta_j^1))((p^2_{jt}/\theta_j^2)/(p^2_{jt-1}/\theta_j^2))$; this expression can be interpreted as the quality adjusted individual index for variety j in period t, therefore substituting this individual index with the remaining ones in (4.1) results in an aggregate price index in which all quality effects have been removed. Similarly, method (c) leads to an aggregate price index which is not subject to distortions arising from quality change, since in this case the index is compiled as in the case when no replacements are made, except that only (n-1) varieties are used in the computations.

In some cases statistical agencies, rather than estimating price indexes using a fixed base approach, use chain index systems and revise the bundles of goods that make up the reference market basket every year. Within a chain index system indexes of price change are first computed for consecutive periods of time, indexes of price change over longer periods of time are compiled by chaining subsequent single period indexes.

If the statistical agency samples n varieties and uses the geometric mean index to aggregate across varieties, the single period rates of price change are computed as:

(4.2) $$P_{t-1,t} = \prod_{i=1}^{n} \left( \frac{p_{it}}{p_{it-1}} \right)^{\frac{1}{n}}$$

The index of the aggregate price level for period t is then computed as:

(4.3) $$P_t = \prod_{\tau=1}^{t} P_{\tau-1,\tau}$$

Because the reference bundle of goods is updated every year with this method, the sample of items used for the calculation of the single period indexes evolves over time due to the introduction of new products and the disappearance of old ones. However, since each single period index is based on price information relative to a given sample of items, it is not subject to the quality change problem, because the qualitative features of any individual item can be assumed to be constant over adjacent time periods. This in turn implies that the resulting chain indexes can be used as indicators of pure price change, quality effects are removed by the chaining procedure.

There are exceptions to this general feature of chain indexes however. For goods characterized by a very rapid pace of technological progress, sample replacements can occur within the course of a year. In this case the above discussion suggests the required quality adjustments should be introduced by using either the overlapping price quotation method, method (b), or the deletion method, method (c).

The above discussion clarifies that the quality adjustment methods used traditionally by statistical agencies are in some cases characterized by the same problems that characterize the construction of hedonic price indexes. In particular, the application of the comparable items method, method (a) (which is also commonly refereed to as "matched model" method) would in general require complete information on the set of performance characteristics of the given product. Since this information is generally not available, the application of this method may result in biased estimates of the rate of price change. The analysis however also shows that there are quality adjustments methods that can be thought to be more reliable, such as the method of overlapping price quotations. Moreover, it shows that the application of methods of measurement based on chain indexes may remove many of the measurement problems related to quality change.

## 5. Estimating hedonic regression functions for automobiles

In order to experiment with the above framework, this section presents empirical estimates of hedonic regression functions compiled using price and characteristics data for automobiles traded in Italy during the period 1988-1998. The analysis is based on the Quattroruote Price and Characteristics Database. An extract of this database is usually published monthly on the Quattroruote magazine which represents a traditional source of information for car customers in Italy.

The database was made available to us directly by Quattroruote in a computer based storage format and contains information on the prices and characteristics of virtually all cars traded in Italy during the 1988-1998 period. Cars in the database are distinguished by brand, model and version. Each brand of car usually produces several models and for each model several versions are available. The version is what ultimately determines the performance characteristics of each automobile. In the following discussion, we will refer to a car as of an automobile identified by brand, model and version, for example: Ford, Fiesta 3rd Series, Fiesta 1.2 i 16V cat. 3 doors Ghia.

The price quotations in the database are list prices inclusive of value added tax, customs duties and other excise taxes. Quattroruote updates these quotations several times a year for each car in the sample, on the basis of information provided by car manufacturers. Given that the hedonic regression analysis was to be performed on an annual basis, the presence of more than one price quotation a year for each car introduced a time aggregation problem in the construction of the dataset to be used for estimation. To solve this problem, we used a simple time aggregation rule, for each year for which a car was priced, the last price quotation for that year was selected as the price measure.

For each car, the database contains information on several technical characteristics. In the present study we follow Raff and Trajtenberg (1997), Gordon (1990), Ohta and Griliches (1976), Triplett (1969) and Griliches (1961) in measuring car quality by two sets of variables. The first set of variables includes measures of car size, weight and power. In particular, we use wheelbase (wheelb) as a measure of size, advertised weight as a measure of weight (weight) and displacement (displ) as a measure of power. The second set of quality indicators consists of dummy variables for the following ten accessories: ABS (abs), driver's airbag (dab), passenger's airbag (pab), electronic drive control (edc), side airbags (sab), automatic suspensions control (asc), sunroof (srf), automatic gear (agr), air conditioning (acn) and power steering (pws). Each dummy variable takes the value one if the accessory is either provided as standard equipment or as supplementary equipment without additional charges and the value zero if the accessory is either not available for the particular car or if it can be provided at an additional charge.

The resulting dataset includes 7'263 cars for the 11 years 1988-1998 and a total of 14'042 observations. The dataset takes the form of an unbalanced panel in that each car stays in the sample for just a few years. In particular, 95 per cent of the cars stay in the sample for three years or less.

Table 1 reports sample averages of the price and characteristics variables by year; note that for each accessory dummy variable, the sample averages can be interpreted as the percentage of cars with the accessory as standard equipment in each year. The table shows that the average car price has more than doubled over the period 1988-1998 but that there also has been an evolution of average physical characteristics. In particular, while average car size has remained roughly constant over time, average weight and average power have increased substantially. In addition, many accessories have gradually become standard equipment for an increasing percentage of cars. The only exceptions are for automatic suspensions control and sunroof. One would therefore expect to see this improvement of car characteristics reflected in car prices.

In order to specify and estimate the hedonic regression model, in addition to the size, weight and power variables and to the accessory dummy variables, we included in the regressions a set of car model dummy variables, one for each model in the sample. The inclusion in the regressions of a set of car model dummy variables implies that the empirical model takes the form of a two-way fixed effects model since both individual and time effects are present[3].

In a first approximation we abstracted from identification of functional form problems. In particular, with reference to the model defined in equations (3.4)-(3.10) we set $\lambda_j$=0 for the size, weight and power variables which therefore enter logarithmically in each regression function; the accessory dummy variables and the car model dummy variables instead enter linearly into each regression function. Wherever required we also made appropriate constant conditional variance assumptions.

When no restrictions are imposed on the structural stability of the regression coefficients, apart from constancy of the conditional variance over individuals, the resulting empirical model can be estimated using ordinary least squares methods and considering each year as a separate cross-section regression. Table 2 reports estimates of these unrestricted hedonic regression functions. For each year, the table displays the estimates of the regression coefficients, and of the related standard errors, for the size, weight and power variables and for the accessory dummy variables. Estimates of the car model dummy variables coefficients are not provided; however the number of car model variables included in each cross-section is reported at the bottom of the table in the row labeled "Effects".

To briefly summarize the regression results, note that most of the characteristics variables enter significantly in each regression and with the expected signs. The only important exception is represented by the size variable whose coefficient is negative in most years, although in most cases it also appears to be not significantly different from zero. Since both the dependent variable and the size, weight and power variables enter logarithmically in each regression, their coefficients can be interpreted as elasticities. Thus, for example, the regressions show that an increase in displacement of 10 per cent is associated on average with an increase in price of the order of 3 per cent, holding constant for other measured

[3] The presence of both individual and time effects introduces an identification problem which, apart from computational aspects, is similar in nature to the problem of valid marginalization discussed in the previous section. For the analysis of the two-way model see Hsiao (1986), Matyas and Sevestre (1992) and Baltagi (1995). Note that at variance with the standard formulation of the two-way model, individual effects are defined here over car models rather than over cars. The particular character of the hedonic regression analysis precludes the possibility of using separate individual effects for each car because the vector of the characteristics of each car is constant over time.

characteristics. Similarly, since the accessory dummy variables enter linearly in each regression, their coefficients measure the approximate percentage difference between the price of a car which includes the accessory as standard equipment and the price of a car which does not. For example, cars which include the ABS braking system as standard were approximately 20 per cent more expensive at the beginning of the sample period and approximately 7 per cent more expensive toward the end of the sample period. The regression estimates thus exhibit some variability over time[4].

Although the above estimates are indicative of a positive price/quality relationship, they are not suitable for the estimation of quality adjusted price indexes. If the regression parameters are stable at least over adjacent time periods, estimating the model as a sequence of cross-sections entails a substantial efficiency loss. On the basis of this consideration we proceeded to test for structural stability of the regression coefficients. The testing procedure was articulated in two stages. In the first stage, the null hypothesis that all regression coefficients are constant over a period of two adjacent years, was tested against the alternative of parameter instability, for each pair of adjacent years. In the second stage, the null hypothesis of parameter stability over the whole time period 1988-1998 was tested against the alternative of parameter instability. All tests assume constancy of the conditional variance over individuals and time and therefore take the form of simple F-tests of structural change.

The results of the tests are reported in table 3 and show that the hypothesis of structural stability is accepted at a 5 per cent significance level for all pairs of adjacent years except 1994-95 and 1997-98; at a 1 per cent significance level the hypothesis is rejected only for the years 1997-98; the hypothesis of structural stability over the entire sample period is however definitely rejected.

These results should essentially reflect the effects of technological progress on car prices. Note in particular, from the year by year cross section regressions, that the coefficient

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[4] Due to the possibility of omission of relevant variables, the coefficients for each characteristic variable included in the regressions, reflect not only the effects on prices of changes in the same variable but also unmeasured influences. This might explain in part the negative result on wheelbase if increases in this variable (which is positively associated with car size) are associated with reductions of car quality along other dimensions.

estimates of the car model dummy variables have a tendency to decline over the 1988-1998 period. This suggests that over the course of time technological progress makes it possible to include many accessories as standard, at smaller additional costs in percentage terms. This interpretation is confirmed by the observation that the percentage of cars including each accessory as standard has a tendency to increase over time as has been described above.

The results of the structural change tests suggest that a set of adjacent years regressions may provide a better basis for estimation than the more constrained pooled model. Estimates of adjacent years regressions for all adjacent periods from 1988-89 to 1997-98 are reported in table 4. The table again displays coefficient estimates and associated standard errors for all the variables except the car model dummy variables, although the number of these variables included in each regression is reported at the bottom of the table.

A comparison of the estimation results reported in this table with those of the single year cross-sections shows that inferences regarding the effects on price of the characteristics variables do not change substantially. This consideration applies in general both to the size, weight and power variables and to the accessory dummy variables. The only notable difference is represented by the estimated coefficients for the size variable, which as in the single year cross-sections, in most years are negative but are now significantly different from zero in most regressions.

At the bottom of table 4, the coefficients on the row labeled "time" represent the estimates of the inflation parameter $\phi_t$ for t=1989,…,1998. The estimated inflation rates appear plausible at first sight and well determined from a statistical point of view.

In order to verify whether additional improvements in efficiency could be made, before concluding the regression analysis we tested the additional hypothesis of equality of the car model dummy coefficients within brands using standard F-tests. The null hypothesis is rejected at both 5 per cent and 1 per cent significance levels in all adjacent regressions. On the basis of this result we decided to stop the regression analysis and to use the quality adjusted inflation rates reported in table 4 for the construction of hedonic price indexes. The next section compares these indexes with alternative quality adjusted price indexes[5].

## 6. An analysis of official automobile prices

In order to analyze how hedonic indexes and the alternative quality adjustment methods most often used by statistical agencies perform in practice, we compare the hedonic index that can be calculated on the basis of the regression analysis performed in the previous section with several alternative price series. We first compare the hedonic index with two series of chain indexes compiled using the same database used in the hedonic regression analysis. The two series are calculated using the geometric mean index and the arithmetic mean index and from the discussion above it follows that the former series in particular should provide a good estimate of the quality adjusted rate of price change. Moreover, we compare the above indexes with an alternative quality adjusted price index compiled by the Research Center Promotor. The latter, which is available only from 1992 onwards, was calculated using a database that is very similar to the database used in the present work and a direct quality adjustment method, method (d), (CSP, 1999, 2001). Finally, we compare all these indexes with the official automobile CPI component produced by Istat for the 1988-1998 period. During those years Istat estimated the CPI using a fixed base method and therefore it probably had to deal quite often with the quality adjustment problem. According to Istat (1994), the quality adjustment methods (a)-(c) were used to estimate the elementary components of the CPI in cases where the pace of product replacement in the market made quality adjustments necessary.

Table 5 reports the levels and the rates of change of each of the above indexes over the 1988-1998 period, the levels are calculated with base 1992=100; the last row of the table reports average annual rates of change calculated with reference to the period 1992-96 for the Promotor index and to the period 1988-96 for all other indexes. We decided to calculate average rates for periods ending in 1996 because for the years 1997 and 1998 the different

[5] Standard F-tests of joint significance of the car model dummies also reject the hypothesis that the car model dummy variables are not jointly significant for all adjacent regressions at both 5 per cent and 1 per cent significance levels.

indexes are not strictly comparable. During these two years, the Italian government introduced several transitory subsidies that had the effect of reducing the price of a new car for customers that decided to scrap their old car to buy a new one. Provisions for the "scrapping incentives" are included in the Promotor index and in the CPI but are not included in our indexes. The yearly rates of change of each index are reproduced graphically in figure 1.

Comparing the hedonic index with the chain indexes, note that the former index increases at approximately the same average annual rate as the latter ones; the average annual rate of change over the 1988-1996 period is about 3.6 percentage points per year. However there are noticeable differences between the yearly rates of change of the hedonic index and the yearly rates of change of the chain indexes. This can be interpreted as an indication that the measurement problems of hedonic indexes discussed previously do in fact play a role in shaping their behaviour although in the present application the distortions do not appear to be substantial at least when averaged over the whole time interval[6].

Next, the index compiled by Promotor has a tendency to overstate the rate of price change with respect to the chain indexes; the distortions characterizing this index appear to be more serious than the ones which seem to characterize the hedonic index. Note that for the years 1997 and 1998 the rate of change of the Promotor index is smaller than the one characterizing the chain indexes but this result is due to differences caused by the scrapping incentives.

Finally, by comparing the official automobile CPI and the chain indexes, note that the CPI increases at an annual average rate of about 5.8 percentage points over the 1988-1996 period. The official automobile CPI therefore overstates the rate of inflation relative to the chain indexes calculated in the present work by a substantial amount, 2.2 percentage points per year. Note also that the distortion is not uniform over the period, it is particularly high in the years 1993-95. Here again we note that because the CPI includes provisions for the

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[6]Note that the arithmetic mean index ( i.e. $P_{t-1,t}=(1/n)\Sigma_i(p_{it}/p_{it-1})$) is always greater than or equal to the geometric mean. This is one of the properties of the two indexes, see Dalén (1992) and Diewert (1995), for an analysis of more axiomatic and economic properties of both indexes. The geometric mean index is preferable in the present context because, given the assumptions of the hedonic regression model, it is characterized by desirable statistical properties.

scrapping incentives, the comparisons lose much of their meaning for the years 1997 and 1998.

One possible source of the discrepancy between the official automobile CPI and the alternative indexes might be due to differences of composition. In order to compute the automobile CPI, Istat adopts a sampling procedure which selects items to price from only the market segments with the highest market share. These market segments correspond to the middle range of the market. The sample of prices used for the alternative indexes instead cover the whole automobile market. However the market segments covered in the CPI represent more than seventy per cent of the automobile market during the period 1988-1998 and therefore the significance of any possible discrepancy due to compositional effects should be relatively small.

A second source of discrepancy can be attributed to the greater volatility that should characterize the official automobile CPI, since it is computed using only a very limited number of price quotations each year.

Overall however, the analysis suggests that the upward drift of the official index might be caused by failures in the application of the quality adjustment procedures used by Istat in cases of sample replacements. One possibility is that some of the sample replacements have been made assuming comparable items (method (a)) and therefore not including any provision for quality change, while in fact quality changes have occurred. A second possibility is that the deletion method has been used (method (c)) with the reduction of individual items included in the official index causing an increase in the volatility of the index. There does not seem to be any source of bias that could be attributable to the overlapping price quotations method (method (b)).

## 7. Conclusions

This paper provides an extension of the repackaging model of quality choice to the case of durable consumption and shows how this model can be used to define quality adjusted price indexes which can be used as indicators of price change and as deflators of nominal durable consumption expenditure. The model is then used to study the problems of empirical estimation of quality adjusted price indexes.

The paper discusses some aspects of the problem of specification and estimation of hedonic regressions functions and hedonic price indexes showing that due to measurement problems, the hedonic regression method cannot always be used to identify and estimate quality adjusted price indexes. The paper also analyzes the alternative quality adjustment methods most commonly used by statistical agencies, showing that some of these methods are characterized by distortions of the same nature as those characterizing hedonic price indexes, while other methods can lead to reliable price measures, although some problems in their application may arise, particularly when price indexes are compiled using a fixed base approach. The analysis suggests in particular that the use of chain index systems should remove many of the measurement problems that are usually associated with fixed base indexes.

The empirical application compares the official automobile CPI compiled by Istat for the period 1988-1998 on the basis of a fixed base method, with a hedonic index compiled using the Quattoruote price and characteristics database and with chain indexes compiled using the same database. A comparison is also made with a quality adjusted price index compiled by the research center Promotor for the period 1992-98 on the basis of a database similar to the Quattroruote database. The results tend to confirm the view that hedonic price indexes are characterized by distortions, although these do not appear to be very large. However, the official automobile CPI substantially overstates the rate of inflation relative to the alternative indexes calculated here.

A plausible explanation for the observed discrepancy between the official and the alternative indexes is that the official index has been compiled using quality adjustment procedures that rely on too limited information regarding the improvement of car quality over the sample period under consideration and as a consequence is subject to quality change bias.

It should be noted that since the beginning of 1999, Istat has compiled the CPI using a chain index system and this methodological change should lead to an improvement in the reliability of official Italian price indexes.

# Tables and Figures

Table 1

## SAMPLE MEANS OF THE PRICE AND CHARACTERISTICS VARIABLES [1]

| | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| price | 21886 | 29138 | 29336 | 30693 | 33107 | 39645 | 39745 | 44701 | 51500 | 56008 | 53343 |
| wheelb | 2.50 | 2.52 | 2.52 | 2.52 | 2.53 | 2.56 | 2.57 | 2.58 | 2.60 | 2.61 | 2.60 |
| weight | 1035 | 1070 | 1075 | 1085 | 1116 | 1187 | 1189 | 1227 | 1278 | 1321 | 1309 |
| displ | 1670 | 1795 | 1763 | 1770 | 1798 | 1930 | 1888 | 1949 | 2033 | 2083 | 2045 |
| abs | 0.093 | 0.168 | 0.181 | 0.223 | 0.271 | 0.372 | 0.400 | 0.452 | 0.531 | 0.623 | 0.648 |
| dab | 0.000 | 0.023 | 0.022 | 0.030 | 0.069 | 0.240 | 0.445 | 0.622 | 0.718 | 0.791 | 0.843 |
| pab | 0.000 | 0.008 | 0.005 | 0.013 | 0.022 | 0.090 | 0.144 | 0.271 | 0.420 | 0.594 | 0.604 |
| edc | 0.000 | 0.013 | 0.011 | 0.018 | 0.027 | 0.029 | 0.041 | 0.082 | 0.169 | 0.273 | 0.249 |
| sab | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.006 | 0.019 | 0.083 | 0.246 | 0.318 |
| asc | 0.010 | 0.069 | 0.063 | 0.067 | 0.086 | 0.086 | 0.086 | 0.073 | 0.078 | 0.075 | 0.091 |
| srf | 0.046 | 0.040 | 0.044 | 0.042 | 0.056 | 0.056 | 0.062 | 0.057 | 0.046 | 0.037 | 0.029 |
| agr | 0.005 | 0.037 | 0.035 | 0.041 | 0.046 | 0.060 | 0.052 | 0.061 | 0.081 | 0.119 | 0.118 |
| acn | 0.067 | 0.092 | 0.108 | 0.144 | 0.199 | 0.273 | 0.337 | 0.419 | 0.508 | 0.562 | 0.646 |
| pws | 0.376 | 0.433 | 0.473 | 0.536 | 0.590 | 0.697 | 0.771 | 0.828 | 0.878 | 0.902 | 0.923 |
| Obs. | 194 | 596 | 915 | 1033 | 1239 | 1391 | 1623 | 1448 | 1701 | 1527 | 2375 |

(1) Prices in thousands of liras.

Table 2

**PARAMETER ESTIMATES OF YEAR BY YEAR CROSS-SECTIONS** (1)

| lprice | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| lwheelb | 1.129 | 0.688 | -0.255 | -0.971 | -0.598 | -0.877 | -1.179 | -1.306 | -0.217 | -0.168 | -0.048 |
| | (1.835) | (0.795) | (0.519) | (0.513) | (0.392) | (0.379) | (0.386) | (0.401) | (0.275) | (0.204) | (0.132) |
| lweight | 2.139 | 1.440 | 1.316 | 1.484 | 1.368 | 1.201 | 1.239 | 1.316 | 1.228 | 0.927 | 0.926 |
| | (0.249) | (0.138) | (0.109) | (0.090) | (0.078) | (0.071) | (0.065) | (0.063) | (0.058) | (0.066) | (0.052) |
| ldispl | 0.005 | 0.235 | 0.310 | 0.278 | 0.277 | 0.327 | 0.362 | 0.302 | 0.352 | 0.372 | 0.338 |
| | (0.083) | (0.048) | (0.038) | (0.034) | (0.030) | (0.026) | (0.025) | (0.023) | (0.019) | (0.021) | (0.016) |
| abs | 0.219 | 0.192 | 0.187 | 0.139 | 0.143 | 0.128 | 0.106 | 0.080 | 0.086 | 0.082 | 0.068 |
| | (0.038) | (0.021) | (0.017) | (0.014) | (0.012) | (0.010) | (0.010) | (0.010) | (0.010) | (0.012) | (0.008) |
| dab | - | -0.054 | -0.037 | -0.013 | 0.055 | 0.014 | 0.015 | 0.043 | 0.058 | 0.044 | 0.003 |
| | - | (0.044) | (0.038) | (0.035) | (0.020) | (0.011) | (0.009) | (0.010) | (0.010) | (0.012) | (0.009) |
| pab | - | 0.215 | -0.106 | 0.033 | 0.003 | 0.050 | 0.048 | 0.041 | 0.015 | -0.002 | 0.035 |
| | - | (0.151) | (0.094) | (0.049) | (0.041) | (0.020) | (0.014) | (0.012) | (0.011) | (0.013) | (0.009) |
| edc | - | 0.216 | 0.110 | 0.100 | 0.131 | 0.128 | 0.087 | 0.027 | 0.016 | 0.057 | 0.045 |
| | - | (0.052) | (0.043) | (0.030) | (0.025) | (0.021) | (0.017) | (0.014) | (0.010) | (0.009) | (0.009) |
| sab | - | - | - | - | - | - | 0.018 | -0.004 | 0.010 | 0.011 | -0.010 |
| | - | - | - | - | - | - | (0.043) | (0.035) | (0.012) | (0.012) | (0.009) |
| asc | 0.056 | 0.023 | 0.051 | 0.090 | 0.103 | 0.064 | 0.020 | 0.014 | -0.006 | 0.034 | 0.045 |
| | (0.089) | (0.031) | (0.026) | (0.022) | (0.019) | (0.014) | (0.013) | (0.015) | (0.012) | (0.013) | (0.012) |
| srf | 0.085 | 0.028 | 0.065 | 0.048 | 0.061 | 0.070 | 0.067 | 0.086 | 0.130 | 0.093 | 0.092 |
| | (0.046) | (0.031) | (0.025) | (0.021) | (0.016) | (0.014) | (0.014) | (0.015) | (0.017) | (0.018) | (0.014) |
| agr | -0.011 | 0.029 | 0.051 | 0.062 | 0.058 | 0.085 | 0.092 | 0.068 | 0.074 | 0.069 | 0.058 |
| | (0.106) | (0.035) | (0.027) | (0.022) | (0.017) | (0.014) | (0.013) | (0.012) | (0.011) | (0.011) | (0.008) |
| acn | 0.157 | 0.136 | 0.133 | 0.107 | 0.127 | 0.142 | 0.121 | 0.095 | 0.092 | 0.099 | 0.068 |
| | (0.044) | (0.024) | (0.017) | (0.014) | (0.011) | (0.010) | (0.008) | (0.007) | (0.007) | (0.008) | (0.006) |
| pws | 0.006 | 0.058 | 0.060 | 0.055 | 0.033 | 0.028 | 0.020 | 0.019 | 0.004 | 0.026 | 0.045 |
| | (0.037) | (0.017) | (0.014) | (0.012) | (0.012) | (0.011) | (0.010) | (0.010) | (0.010) | (0.011) | (0.010) |
| const | -5.333 | -1.651 | -0.220 | -0.405 | -1.389 | 0.306 | 0.147 | 0.195 | -0.588 | 1.440 | 1.624 |
| | (2.051) | (0.939) | (0.807) | (0.729) | (0.480) | (0.567) | (0.544) | (0.548) | (0.423) | (0.403) | (0.311) |
| Obs. | 194 | 596 | 915 | 1033 | 1239 | 1391 | 1623 | 1448 | 1701 | 1527 | 2375 |
| Effects | 42 | 89 | 110 | 118 | 119 | 140 | 146 | 149 | 166 | 179 | 221 |
| $R^2$ | 0.96 | 0.98 | 0.97 | 0.98 | 0.98 | 0.98 | 0.97 | 0.98 | 0.98 | 0.98 | 0.98 |
| Root MSE | 0.098 | 0.100 | 0.102 | 0.097 | 0.098 | 0.093 | 0.097 | 0.088 | 0.086 | 0.086 | 0.087 |

(1) OLS parameter estimates and standard errors. Standard errors are given in parenthesis. The variables lprice-ldispl are the natural logarithms of the price, size, weight and power variables. The row labeled Effects reports the number of car model effects in each cross section.

Table 3

**STRUCTURAL CHANGE TESTS**

| | F | Numerator Degrees of Freedom | Denominator Degrees of Freedom | p-value |
|---|---|---|---|---|
| 1988-89 | 0.6253 | 50 | 636 | 0.9800 |
| 1989-90 | 0.7427 | 98 | 1286 | 0.9700 |
| 1990-91 | 0.5434 | 113 | 1694 | 1.0000 |
| 1991-92 | 1.0231 | 121 | 2009 | 0.4160 |
| 1992-93 | 0.9090 | 123 | 2345 | 0.7515 |
| 1993-94 | 1.0431 | 132 | 2701 | 0.3539 |
| 1994-95 | 1.2218 | 140 | 2748 | 0.0426 |
| 1995-96 | 0.9949 | 140 | 2806 | 0.5020 |
| 1996-97 | 1.1705 | 140 | 2855 | 0.0880 |
| 1997-98 | 1.3295 | 166 | 3474 | 0.0037 |
| 1988-98 | 2.3104 | 1240 | 12418 | 0.0000 |

Table 4

**PARAMETER ESTIMATES OF ADJACENT YEARS REGRESSIONS** (1)

| lprice | 1988-89 | 1989-90 | 1990-91 | 1991-92 | 1992-93 | 1993-94 | 1994-95 | 1995-96 | 1996-97 | 1997-98 |
|---|---|---|---|---|---|---|---|---|---|---|
| lwheelb | 0.631 | -0.010 | -0.719 | -0.914 | -0.621 | -1.137 | -1.205 | -0.602 | -0.306 | -0.141 |
| | (0.715) | (0.423) | (0.356) | (0.300) | (0.267) | (0.267) | (0.276) | (0.225) | (0.162) | (0.111) |
| lweight | 1.599 | 1.319 | 1.391 | 1.391 | 1.292 | 1.217 | 1.283 | 1.271 | 1.097 | 0.930 |
| | (0.118) | (0.084) | (0.068) | (0.057) | (0.052) | (0.047) | (0.045) | (0.042) | (0.042) | (0.041) |
| ldispl | 0.183 | 0.292 | 0.301 | 0.293 | 0.305 | 0.351 | 0.336 | 0.335 | 0.364 | 0.353 |
| | (0.041) | (0.029) | (0.024) | (0.022) | (0.020) | (0.018) | (0.017) | (0.015) | (0.014) | (0.013) |
| abs | 0.197 | 0.193 | 0.154 | 0.139 | 0.133 | 0.115 | 0.097 | 0.087 | 0.081 | 0.071 |
| | (0.018) | (0.013) | (0.010) | (0.009) | (0.008) | (0.007) | (0.007) | (0.007) | (0.007) | (0.006) |
| dab | -0.049 | -0.050 | -0.022 | 0.036 | 0.017 | 0.010 | 0.030 | 0.047 | 0.048 | 0.015 |
| | (0.043) | (0.028) | (0.025) | (0.017) | (0.009) | (0.006) | (0.006) | (0.007) | (0.008) | (0.007) |
| pab | 0.181 | -0.029 | -0.002 | -0.002 | 0.030 | 0.032 | 0.034 | 0.024 | 0.000 | 0.022 |
| | (0.147) | (0.077) | (0.042) | (0.028) | (0.016) | (0.010) | (0.008) | (0.007) | (0.008) | (0.007) |
| edc | 0.212 | 0.143 | 0.104 | 0.116 | 0.136 | 0.108 | 0.052 | 0.018 | 0.045 | 0.050 |
| | (0.050) | (0.032) | (0.024) | (0.018) | (0.016) | (0.013) | (0.011) | (0.008) | (0.006) | (0.006) |
| sab | - | - | - | - | - | 0.004 | 0.016 | 0.010 | 0.021 | -0.003 |
| | - | - | - | - | - | (0.035) | (0.025) | (0.011) | (0.007) | (0.007) |
| asc | 0.019 | 0.036 | 0.074 | 0.099 | 0.077 | 0.038 | 0.012 | 0.003 | 0.012 | 0.036 |
| | (0.028) | (0.019) | (0.017) | (0.014) | (0.012) | (0.010) | (0.010) | (0.009) | (0.009) | (0.009) |
| srf | 0.044 | 0.070 | 0.053 | 0.047 | 0.068 | 0.066 | 0.076 | 0.103 | 0.120 | 0.094 |
| | (0.025) | (0.019) | (0.016) | (0.012) | (0.010) | (0.010) | (0.010) | (0.011) | (0.012) | (0.011) |
| agr | 0.020 | 0.049 | 0.062 | 0.059 | 0.074 | 0.089 | 0.082 | 0.069 | 0.071 | 0.062 |
| | (0.032) | (0.021) | (0.017) | (0.014) | (0.011) | (0.010) | (0.009) | (0.008) | (0.007) | (0.006) |
| acn | 0.144 | 0.127 | 0.116 | 0.112 | 0.135 | 0.127 | 0.106 | 0.091 | 0.091 | 0.077 |
| | (0.020) | (0.014) | (0.010) | (0.009) | (0.007) | (0.006) | (0.006) | (0.005) | (0.005) | (0.005) |
| pws | 0.046 | 0.059 | 0.058 | 0.046 | 0.031 | 0.024 | 0.020 | 0.014 | 0.014 | 0.039 |
| | (0.015) | (0.010) | (0.009) | (0.008) | (0.008) | (0.007) | (0.007) | (0.007) | (0.007) | (0.007) |
| time | 0.053 | 0.026 | 0.020 | 0.035 | 0.050 | 0.038 | 0.042 | 0.017 | 0.014 | -0.010 |
| | (0.009) | (0.006) | (0.005) | (0.004) | (0.004) | (0.004) | (0.004) | (0.003) | (0.004) | (0.003) |
| const | -2.325 | -1.031 | -1.187 | -0.261 | -0.496 | 0.287 | 0.037 | -0.417 | 0.394 | 1.569 |
| | (1.004) | (0.591) | (0.447) | (0.396) | (0.399) | (0.384) | (0.383) | (0.329) | (0.279) | (0.244) |
| Obs. | 790 | 1511 | 1948 | 2272 | 2630 | 3014 | 3071 | 3149 | 3228 | 3902 |
| Effects | 90 | 113 | 127 | 128 | 148 | 166 | 168 | 188 | 218 | 247 |
| $R^2$ | 0.97 | 0.97 | 0.98 | 0.97 | 0.98 | 0.97 | 0.97 | 0.98 | 0.98 | 0.98 |
| Root MSE | 0.098 | 0.100 | 0.098 | 0.098 | 0.095 | 0.095 | 0.093 | 0.087 | 0.086 | 0.087 |

(1) OLS parameter estimates and standard errors. Standard errors are given in parenthesis. The variables lprice-ldispl are the natural logarithms of the price, size, weight and power variables. The row labeled Effects gives the number of car model effects in each cross section.

Table 5

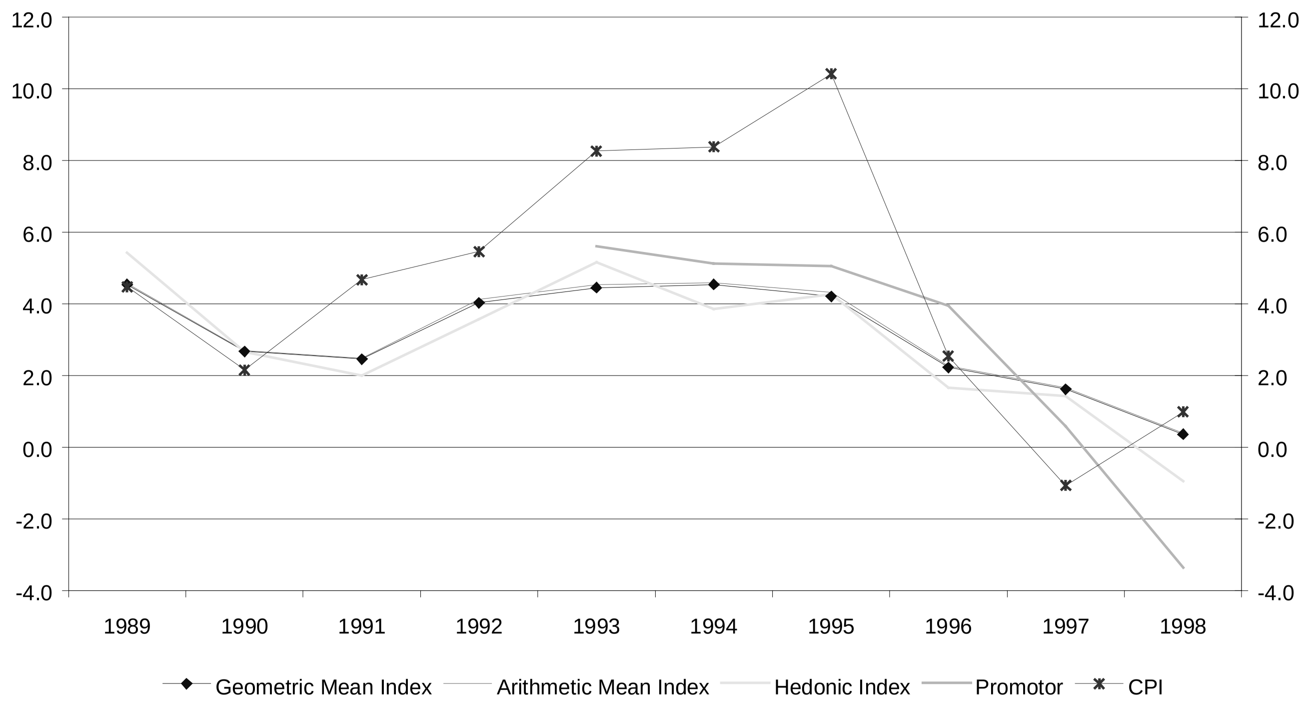
## ALTERNATIVE QUALITY ADJUSTED PRICE INDEXES [1]

| | Geometric Mean Index | | Arithmetic Mean Index | | Hedonic Index | | Promotor | | CPI | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1988 | 87.4 | | 87.3 | | 87.5 | | | | 84.9 | |
| 1989 | 91.4 | 4.5 | 91.3 | 4.6 | 92.2 | 5.4 | | | 88.7 | 4.5 |
| 1990 | 93.8 | 2.7 | 93.7 | 2.7 | 94.7 | 2.7 | | | 90.6 | 2.2 |
| 1991 | 96.1 | 2.5 | 96.0 | 2.5 | 96.6 | 2.0 | | | 94.8 | 4.7 |
| 1992 | 100.0 | 4.0 | 100.0 | 4.1 | 100.0 | 3.6 | 100.0 | | 100.0 | 5.5 |
| 1993 | 104.4 | 4.4 | 104.5 | 4.5 | 105.1 | 5.1 | 105.6 | 5.6 | 108.3 | 8.3 |
| 1994 | 109.2 | 4.5 | 109.3 | 4.6 | 109.2 | 3.9 | 111.0 | 5.1 | 117.3 | 8.4 |
| 1995 | 113.8 | 4.2 | 114.0 | 4.3 | 113.8 | 4.3 | 116.6 | 5.0 | 129.5 | 10.4 |
| 1996 | 116.3 | 2.2 | 116.6 | 2.3 | 115.7 | 1.7 | 121.2 | 3.9 | 132.8 | 2.5 |
| 1997 | 118.2 | 1.6 | 118.6 | 1.6 | 117.4 | 1.4 | 121.9 | 0.6 | 131.4 | -1.1 |
| 1998 | 118.6 | 0.4 | 119.0 | 0.4 | 116.3 | -1.0 | 117.8 | -3.4 | 132.7 | 1.0 |
| 1988-96 | | 3.6 | | 3.7 | | 3.6 | | 4.9 | | 5.8 |

(1) For each index, levels in base 1992=100 are given in the first column, rates of change are given in the second column. The last row gives average annual rates of change calculated with reference to the 1992-96 period for the index compiled by Promotor and to the 1988-1996 period for all other indexes.

Figure 1

RATES OF CHANGE OF ALTERNATIVE QUALITY ADJUSTED PRICE INDEXES



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