ASSESSING THE QUALITY ERROR IN OUTPUT MEASURES: THE CASE OF REFRIGERATORS*

BY JACK E. TRIPLETT AND RICHARD J. MCDONALD

U.S. Bureau of Labor Statistics

This paper computes new indexes of output for refrigerators, using hedonic methods to adjust for quality change. The hedonic technique is applied in a new way (it is used to make quality adjustments to prices before they are used in the index), and the results are compared with those from methods used in previous hedonic investigations.

There are three major findings. (1) Overall (1960–1972), our hedonic deflated output series rise more rapidly than conventional measures, because the price indexes used for deflation rise more slowly. (2) The output measures fluctuate more than do output measures produced by conventional methods, because adding hedonic quality adjustments to WPI indexes moves them up in some years and down in others, and the resulting adjustments to the output series were positively correlated with changes in output. (3) Applying methods used in previous studies produces larger adjustments to the published indexes, suggesting that some of the differences noted in previous studies between hedonic indexes and official published indexes are related to computational methods, not to quality adjustment.

I. INTRODUCTION

Economists are accustomed to using output measures as if they corresponded to the physical quantities dealt with in the theory of production. However, most output data in the National Accounts and in other economic measurements are not based on physical quantities, but rather are derived from value data (such as value of shipments) through deflation by appropriate price indexes.

Under the deflation method for calculating real output, any error in the price indexes causes an equivalent error (of opposite sign) in the output measures. Quality change has long been acknowledged as a major potential source of price index error,[1] and may therefore bias measures of real output. The present paper was stimulated, in part, by the U.S. Productivity Commission's interest in determining whether official measures of output per employee hour were biased because of quality error in the output figures.

We chose to examine output, output per employee hour, and price measures for the major household appliances industry, partly because it is an important

*The research for this paper was supported, in part, by the U.S. Productivity Commission. We wish to acknowledge the contributions of David C. Lund and Dale A. Smith, who participated in the research, research assistance by Mary Burns and Susan G. Sammarco, and helpful comments from Zvi Griliches and Owen Sauerlender. The project could not have been completed without advice and guidance on construction of the original data series from the staffs of the BLS Office of Productivity and Technology and Office of Prices and Living Conditions. Views expressed are those of the authors and do not reflect official positions by the U.S. Bureau of Labor Statistics or the U.S. Productivity Commission.

[1]There is an extensive literature on this subject. See the bibliography in Griliches, ed. (1971), and also the survey by Triplett (1975).

consumer goods industry, in which innovation and quality change have been rapid. In addition, several intriguing trends in the published statistics for this industry make it an apt subject for investigation.

The statistical picture presented by existing appliance industry data shows high rates of growth in output and in output per employee hour, and prices which have fallen relative to other manufactured consumer goods. The Consumer Price Index for appliances, and for refrigeration equipment (the largest appliance subindustry), declined *every single year* between 1951 and 1966 (Table 1), with somewhat smaller declines in the Wholesale Price Index component. Moreover, the subsequent rise in these indexes has been far more modest than increases in the overall CPI and WPI, or their consumer durables components. However, the magnitude of measured price decline (and the steep growth of deflated output, and output per employee hour) depends on the very high rate of quality change implicit in the data, and therefore on our notoriously imperfect ability to adjust for the value of quality change.

Two published studies suggest that appliance price indexes may have declined too rapidly (which implies that output measures may have overstated real growth). Burstein (1961), in an article based on data assembled for his earlier study on refrigerator demand (1960), concluded that quality error in refrigerator price indexes imparts a downward bias.[2] Dhrymes (1971, page 117) estimates that quality-adjusted refrigerator prices fell "in the neighborhood of" 3 percent per year from 1950–1965. Since the CPI fell 4.4 percent per year, on average, over the same years (calculated on the same basis as was Dhrymes' number), Dhrymes' results are also consistent with downward quality bias in the CPI refrigerator index.[3]

Pitted against the Burstein and Dhrymes results is a paper by Robert J. Gordon (1971), who carried out two relevant computations. The first used data taken from Burstein (1960), and supported, Gordon argued, the conclusion that the CPI refrigerator index was upward—not downward—biased because of quality change.[4] In his second computation Gordon (1971, page 146) computed an "average price per cubic foot" for refrigerators, using specifications and approximate retail prices given in *Consumer Reports*. Gordon's *Consumer Reports*

[2]"The [refrigerator price] index ignoring quality changes fell more than the index adjusted for such changes with reporting procedures held constant." Burstein (1961), page 279.

[3]See also Dhrymes (1967), Table 7, page 118 (column headed "P_1"). This presents a quality-adjusted refrigerator price index that is nearly trendless between the early 1950s and 1964 (a period in which the CPI and WPI fell steadily), though Dhrymes' index drops sharply (and inexplicably) in 1965.

[4]Gordon presents (in Table 4 on page 144 of his article) four different "estimates of price index bias" for refrigerators, to three of which he attaches Burstein's name. Moreover, the text asserts that Gordon and Burstein are in agreement ("My implied CPI bias . . . is very similar to Burstein's"—page 146). The indexes Gordon used were taken from Burstein's 1960 article on the demand for refrigerators, and in a footnote to the table in which these data were presented, Burstein remarks on the "close correspondence" between the CPI and his mail-order refrigerator price indexes (Burstein, 1960, Table A6, page 134). In his later article, Burstein concluded that omission of quality adjustments would bias the indexes downward. In short, Gordon and Burstein are not in agreement on this issue at all, even though conclusions of both parties rest on Burstein's data. One might argue with Burstein's interpretation of his own data, and reinterpret them, as Gordon has done. But nowhere does Gordon notify the reader that Burstein himself, in an article explicitly on the subject of quality error in price indexes (Burstein, 1961), concluded that his own refrigerator data support a conclusion diametrically opposed to the one Gordon's paper attributes to Burstein (see footnote 2, above).

computation can be interpreted as a less sophisticated version of the hedonic methodology of the present paper; the version we use gives different results.[5]

TABLE 1
PRICE INDEXES FOR REFRIGERATORS AND REFRIGERATOR-FREEZERS (1967 = 100)

Year	CPI Appliances (excluding Radio and TV)	CPI Refrigerator and Refrigerator-Freezer	WPI Refrigerator	WPI Refrigerator-Freezer
1947	130.5	174.5	121.5	
1948	141.0	192.7	130.2	
1949	137.9	186.8	126.7	
1950	135.1	182.7	129.1	
1951	143.8	192.4	132.4	
1952	141.9	185.1	131.8	
1953	140.4	178.1	133.1	
1954	135.9	166.0	134.1	
1955	129.3	156.0	128.0	
1956	120.1	134.6	123.7	
1957	117.7	123.8	116.6	
1958	113.8	119.6	114.3	
1959	113.6	119.2	114.0	
1960	112.1	116.8	108.7	
1961	109.8	115.2	105.2	119.4
1962	107.2	112.5	102.0	115.3
1963	105.2	109.6	98.7	107.8
1964	104.0	107.4	98.2	104.0
1965	101.6	104.2	96.6	102.4
1966	99.9	100.2	97.6	100.5
1967	100.0	100.0	100.0	100.0
1968	102.1	101.3	104.3	103.4
1969	104.3	103.1	105.3	105.0
1970	106.9	105.8	107.4	106.1
1971	109.1	108.1	n.a.	108.1
1972	109.7	108.1	n.a.	105.3

Source: Compiled from BLS historical records.
WPI Refrigerator-Freezer index introduced in 1961, Refrigerator Index terminated in 1970.

In the present study, we use data derived from a hedonic study on refrigerator-freezers to produce a quality-adjusted price index. However, we employ the hedonic results in a new way, one which we believe produces a more precise answer to the question asked. Adjustments based on the hedonic functions developed in Section II are applied to WPI price quotes, to produce new, quality-adjusted indexes in Section III. Section IV compares our method with results from procedures used in previous hedonic studies. Finally, in Section V we use the reconstructed refrigerator price indexes from Section III to estimate new output (and output per employee hour) series for the appliance industry.

[5]Gordon's (1971) average price per cubic foot calculation can be interpreted as a one variable hedonic function, forced through the origin. Our results indicate that the incremental price for refrigeration capacity is lower than the average price. Moreover, when other quality variables are introduced, the estimate of the implicit price for an incremental cubic foot of refrigerator capacity falls. For these reasons, Gordon's average price per cubic foot measure, when used to quality adjust refrigerator prices for *capacity increases*, overadjusts greatly. Another difference between Gordon's estimate and ours is that he tried to estimate the quality bias in the WPI by constructing a quality-adjusted *retail* price index.

II. A Hedonic Study of Refrigerators

There are four different appliance subindustries which make up the major appliance group—cooking equipment, refrigeration equipment, laundry equipment, and "appliances not elsewhere classified." Each subindustry is composed of a number of product lines. Refrigeration equipment receives about 50 percent of the weight in the appliance industry, and refrigerator-freezers account for about 70 percent of the refrigeration equipment weight, so the subject of our hedonic study covers about 35 percent of the major household appliance industry.

We have chosen to pursue the "hedonic" technique as a device for controlling for quality change. Hedonic quality measures rest on the proposition that the term "quality" can best be understood as a kind of shorthand reference to the *quantities* in a vector of product "characteristics" (the term is used in the sense of Lancaster, 1971). The hedonic technique—which is nothing more than a tool for determining the prices of characteristics—is the mechanism for valuing changes in quantities of characteristics.[6]

Empirical procedures for conducting hedonic studies have now become more or less standard, and need not be described here (see Griliches, 1971). Three aspects of our investigation which warrant special emphasis are discussed in the following paragraphs.

Data Base, Choice of Variables, and Functional Form

(1) Hedonic studies require extensive cross-sections of specifications and prices for a range of varieties of the product. Most investigations similar to the present one have employed a price data base entirely different from the one used for the published BLS indexes. Dhrymes (1971), for example, used the hedonic technique to compute a quality-adjusted refrigerator price index based on "suggested retail list" prices taken from trade sources. Such indexes may differ from published BLS indexes because of the price data base (and for other reasons as well), so deviations between research indexes and official BLS indexes may be attributable to a variety of factors aside from quality measurement. In the present study, we sought to minimize the non-comparability problem.

The best price data for our purposes would consist of manufacturer's transactions prices, comparable to WPI price quotes. However, the number of refrigerator-freezer prices collected for the WPI is far too small to estimate reliable hedonic functions, so we split the investigation into two parts. For the hedonic regressions, we use cross-sections of retail prices (from those in Dzick, 1972, and Triplett, 1966) as dependent variables. We used alternative sets of retail prices (and also alternative data sources on specifications) to explore the robustness of the regression estimates to different data sets.

In the second phase, we applied factors from the cross-section hedonic regressions to quality adjust the actual refrigerator prices collected for the WPI. The quality-adjusted price indexes presented in this paper therefore differ from

[6]For more information on the hedonic technique, see Griliches (1971) and the items cited in the bibliography contained therein, and also (for the specific context within which this summary statement is written) Triplett (1976).

the WPI refrigerator component *only* in the incorporation of hedonic quality adjustments.

(2) In many of the existing hedonic studies, variables were employed that were rough proxies for quality characteristics, though not necessarily desired for their own sakes. We felt more confident in quality adjustments based on variables whose relationship to quality was fairly clear. We consulted *Consumer Reports* to draw up a list of characteristics on which to base the statistical analysis, although we were not always able to obtain measure of all characteristics we wanted, and some characteristics mentioned by *Consumer Reports* turned out to be relatively unimportant as explanators of price variance in the sample. The reader will note, however, the absence from our list of explanatory variables of several performance characteristics regularly tested and emphasized by *Consumer Reports* (including durability, reliability, and the ability to retain a true zero temperature in the freezer compartment). We have no usable data on these characteristics,[7] though some of them may be related to the company effects that emerged in our regressions.

Our specifications data were drawn from trade sources. The block of specifications and price data that we used for the final results permitted us to do annual cross-sections for the years 1963–65 and 1969–72. A detailed description of the data is contained in an appendix available from the authors.

(3) Specifying a functional form for the hedonic function has until recently been treated as almost purely an empirical question. Although some theoretical speculation on this question has appeared, we believe it has little relevance for conducting hedonic studies, and therefore continue to use the criteria of simplicity of structure and goodness of fit.[8]

Estimation of the Hedonic Quality Function

Annual cross-section regressions were run on all alternative data sets and years, but to conserve space, we have not presented results from single-year regressions (which were used only to isolate quality variables, perform functional form tests, etc.). The quality adjustments which we applied to the WPI index were derived from three pooled regressions, covering the years 1963–65, 1969–72 and 1970–72. The coefficient estimates for these three pooled regressions are presented in Table 2, with estimated company effects arrayed in Table 3.

[7] *Consumer Reports* does not test very many refrigerators at one time, so their tests present no data for most of the machines in our samples.

[8] Muellbauer (1974) and Lucas (1975) have attempted to specify theoretically appropriate functional forms for hedonic studies. Two issues are entwined in these two papers. The first is: If hedonic functions express the market relation between characteristics and prices, what functional forms are appropriate? We feel that neither paper has direct empirical implications for the forms hedonic functions can take, for reasons discussed in Rosen (1974) and Triplett (1976). The second issue relates to the use of hedonic prices in cost-of-living indexes. Much of Muellbauer's paper is concerned with specifying conditions under which hedonic prices can be used in "true" cost-of-living indexes (sometimes called "constant-utility" price indexes). Construction of such indexes always requires specification of the form of the utility function (see Pollak, 1971, and Samuelson–Swamy, 1974), and Muellbauer's paper can best be considered as a contribution to the theory of the cost-of-living index when utility functions are defined on Lancastrian characteristics. But this has nothing directly to do with the form of hedonic functions.

TABLE 2

REGRESSION COEFFICIENTS USED TO MAKE QUALITY ADJUSTMENTS IN THE REFRIGERATOR-FREEZER PRICE INDEX[a]

	1963–65 Pooled Regression		1969–72 Pooled Regression		1970–72 Pooled Regression	
Quality Variables[b]	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
Refrigerator Compartment Capacity	0.054	0.007	0.041	0.003	0.033	0.003
Freezer Capacity	0.075	0.008	0.055	0.004	0.053	0.004
Meat Pan	0.048	0.017	0.060	0.009	0.021	0.011
No Frost or Automatic	0.170	0.016	0.144	0.013	0.108	0.014
Automatic Ice-Maker	0.162	0.022	0.126	0.008	0.119	0.009
Bottom Freezer Location	0.133	0.021	0.074	0.019	0.083	0.026
Side Freezer Location	0.114	0.044	0.198	0.015	0.200	0.018
Power Miser	*	*	*	*	0.040	0.017
Cantilever Shelves	*	*	*	*	0.069	0.011
Reversible Doors	*	*	*	*	0.006	0.014
Rollers	*	*	*	*	0.023	0.011
R^2	0.907		0.956		0.968	
Standard Error of Residual	0.112		0.068		0.059	
Sample Size	303		522		369	

Dependent variable is the natural logarithm of price.

[a]Estimates of intercepts and company effects are in Table 3.

[b]Capacity measures are in cubic feet; all other variables are dummy variables, indicating presence or absence of the characteristic.

*Data on these variables not available before 1970.

Experimentation led us to four conclusions about the hedonic function for refrigerator-freezers. First, the semi-logarithmic form consistently provided a better fit to the data that did the linear form;[9] thus, all the regressions we report are of the semi-log form.

Second, after considerable experimentation with the set of variables for which we could obtain reasonably good data, we settled on the following characteristics: freezer volume, refrigerator compartment volume, and dummy variables for the presence of meat pan, for "no-frost" or automatic defrosting of the freezer compartment, for an automatic ice-maker, and for the location of the freezer compartment (top, bottom, or side). For the 1970–72 period, four additional characteristics that became available entered the regressions—dummy variables for presence of cantilever shelves, for reversible doors, for roller mounting, and for a "power-miser" switch.

Third, we concluded that values of estimated regression coefficients were not unreasonable, on *a priori* considerations. As indicated by the regression coefficients in Table 2 (coefficients for single-year regressions show similar patterns), an

[9]We applied the procedure for comparison of functional forms developed by Box and Cox (1964).

TABLE 3

ESTIMATES OF INTERCEPTS AND COMPANY EFFECTS FROM REFRIGERATOR-FREEZER REGRESSIONS[a]

	1963–65 Pooled Regression			1969–72 Pooled Regression				1970–72 Pooled Regression		
	1963	1964	1965	1969	1970	1971	1972	1970	1971	1972
Intercept	5.049			4.884				5.073		
	(0.076)			(0.029)				(0.033)		
Admiral	−0.301	n.a.	−0.438	−0.019	−0.016	0.115	0.129	−0.093	0.006	0.028
	(0.050)		(0.053)	(0.027)	(0.027)	(0.030)	(0.027)	(0.025)	(0.027)	(0.026)
Amana	0.141	n.a.	0.001	0.045	0.141	0.222	0.241	0.044	0.114	0.121
	(0.052)		(0.047)	(0.028)	(0.026)	(0.025)	(0.035)	(0.028)	(0.027)	(0.035)
Frigidaire	0.130	0.141	0.039	0.325	0.119	0.049	0.119	0.030	−0.022	0.053
	(0.052)	(0.050)	(0.047)	(0.029)	(0.038)	(0.071)	(0.028)	(0.034)	(0.062)	(0.026)
General Electric	b	−0.229	−0.273	b	0.077	0.038	0.009	b	−0.057	−0.086
		(0.050)	(0.049)		(0.023)	(0.026)	(0.026)		(0.023)	(0.024)
Gibson	0.082	−0.368	−0.473	−0.026	−0.039	0.022	0.026	−0.139	−0.074	−0.067
	(0.054)	(0.051)	(0.050)	(0.027)	(0.035)	(0.038)	(0.024)	(0.031)	(0.034)	(0.022)
Hotpoint	−0.012	n.a.	−0.338	−0.035	0.030	n.a.	0.002	−0.054	n.a.	−0.097
	(0.050)		(0.045)	(0.024)	(0.026)		(0.027)	(0.024)		(0.025)
Kelvinator	−0.014	−0.097	−0.222	0.075	0.107	0.130	0.106	0.043	0.044	0.008
	(0.053)	(0.048)	(0.043)	(0.023)	(0.025)	(0.023)	(0.023)	(0.023)	(0.021)	(0.022)
Norge	0.134	−0.327	−0.415	−0.038	0.005	0.028	−0.004	−0.088	−0,080	−0.095
	(0.052)	(0.055)	(0.045)	(0.024)	(0.028)	(0.051)	(0.024)	(0.026)	(0.045)	(0.022)
Philco	0.011	−0.067	−0.281	−0.062	0.036	0.081	0.080	−0.070	−0.042	−0.054
	(0.048)	(0.049)	(0.051)	(0.022)	(0.022)	(0.025)	(0.024)	(0.026)	(0.027)	(0.026)
Westinghouse	n.a.	n.a.	−0.326	0.003	0.023	0.125	0.149	−0.085	0.051	0.053
			(0.046)	(0.033)	(0.026)	(0.043)	(0.025)	(0.024)	(0.038)	(0.023)
Whirlpool	−0.231	n.a.	−0.237	−0.008	0.006	0.035	0.056	−0.089	−0.041	−0.016
	(0.046)		(0.052)	(0.023)	(0.023)	(0.025)	(0.024)	(0.022)	(0.025)	(0.024)

Standard errors are in parentheses.
n.a. No observations available for these cells.
[a]Regression coefficients for quality variables are in Table 2.
[b]This dummy variable dropped to avoid singularity. Thus company effects are measured with this cell as a base.

incremental cubic foot of refrigerator space added from 3 to 5 percent to the price of a refrigerator-freezer, and the price per (incremental) cubic foot fell over the period studied (though not consistently on a year-by-year basis). We can reject the hypothesis that units of refrigeration and of freezer capacity sell for the same price: On average, an incremental cubic foot of freezer capacity cost about 50 percent more than an incremental cubic foot in the refrigeration compartment and the price difference is statistically significant in all three regressions. The freezer price, as with the price of refrigerator space, fell over the 1963–1972 period (though the decline was somewhat erratic).

Other variables were entered as dummy variables, denoting the presence or absence of the characteristic. The coefficients on several of these (including the "no-frost" and automatic ice-maker features) seem to us too high. Very likely, they incorporate the effects of other features which are positively correlated with them in the sample, but which, for one reason or another, we have not been able to include in the regressions, or which did not emerge with statistically significant coefficients in the presence of other explanatory variables. The inclusion of additional variables which first became available in 1970 lowered values of all but the freezer location coefficients, and in addition reduced the standard error of the residual by over 10 percent.

Finally, there were persistent company or brand-name effects in our regressions (determined by introducing a vector of dummy variables for the various refrigerator manufacturers for each year), regardless of the set of explanatory variables employed (see Table 3). The inclusion of company effects reduced the standard error of the residual by amounts ranging from 34 to 88 percent; the most dramatic decreases occurred in the 1963–64 interval (which was also the period in which the estimates of company effects showed the greatest year-to-year instability).

III. The Hedonic Quality-Adjusted Refrigerator-Freezer Price Indexes

In previous comparable studies, the hedonic technique was used to compute a quality-adjusted price index from some data base (typically, published list prices) different from the one gathered for the indexes. In most instances, any difference between the investigator's index and the appropriate published BLS series was attributed to quality change. In fact, however, "quality errors" which have been estimated in such a fashion are actually an amalgam of quality error, differences in movement between the investigator's price series and data collected by the BLS, and the effect of different methods of index construction.

We avoid the non-comparability problem by using results from our hedonic quality study to derive explicit quality adjustments which are applied to the actual prices collected for the WPI refrigerator-freezer index. Thus, our recomputed price indexes differ from those originally used for deflating output *only* in the method for handling quality change. Our indexes, therefore, answer a narrowly—but precisely—defined question, namely: How would the output measures have differed had hedonic quality adjustments been employed in the price indexes, rather than the quality-adjustment methods that were in fact used?

As participation by manufacturers in WPI pricing is voluntary and contingent on the confidentiality of their responses, it is not possible for us to present the individual adjustments that were made. Instead, we have contrived an example to illustrate our adjustment procedure. Suppose that in a given month the following changes occurred on a refrigerator priced for the index: the price rose from \$180 to \$200, net refrigerated volume increased by 1.2 cubic feet, and a meat pan was added. Using estimated implicit prices from the 1970–72 regression of Table 2, we can estimate a quality-adjusted price for the new machine, based on the final price of the old machine:

$$\$180 \times \exp(0.033 \times 1.2 + 0.021) = \$191.25$$

Thus of the \$20 change in price, we would attribute \$11.25 to quality change and the remaining \$8.75 to pure price change. Note that with the semi-log form of the hedonic function implicit prices for characteristics are estimated in percentage form; accordingly, application to WPI prices of quality factors estimated from regressions on *retail* price data requires only the assumption that percentage mark-ups are uncorrelated with characteristics proportions.

We made no use of the company effects of Table 3 in computing our hedonic-adjusted WPI.[10] Prices for refrigerators from different manufacturers are never compared directly in the WPI, so it was not necessary for us to consider using the company effects for inter-brand comparisons. In our regressions, however, company effects differed—sometimes substantially— from one year to the next (see Table 3). For example, the company effect for Fridgidaire fell nearly 19 percent between 1969 and 1970, declined again in the following year, then rose sharply between 1971 and 1972. The company effect for Amana, on the other hand, rose in all three years. For our purposes, therefore, the problem was whether to consider changes in the yearly company effects for *intra*-company comparisons.

Intra-brand company effects should be incorporated into our hedonic-adjusted WPI only if year-to-year changes in them are caused by changes in chracteristics omitted from our hedonic functions, and even then only if changes in omitted characteristics on the (single) model priced for the WPI were prevalent in the company's entire production. We attempted to explore the omitted characteristics explanation for company effects by relating them to performance data from *Consumer Reports* on characteristics such as durability, freezer temperature, and electricity use, but results were inconclusive. We have already noted that the company effects sometimes fluctuated widely; if these changes were caused by changes in the omitted quality characteristics, it would have required more frequent and radical product redesign than we have observed for the refrigerators in our sample.[11] Though we have no direct evidence, we doubt if year to year changes in company effects are associated with omitted quality characteristics.

Company effects may also be measuring the effects of pricing errors. If so, we would not want to adjust such price changes out of the index. In addition, the price data we used for our final regressions are "suggested" retail prices, so the company effects may be picking up systematic differences in the way these prices are generated (i.e., differences in the relation between actual transactions prices and suggested list prices).

Accordingly we made no use of the company effects in adjusting WPI price quotes. We did, however, take our adjustment factors from regressions which included company effects, because statistical tests revealed them relevant and important.

To carry out the quality adjustments, it was necessary to determine the specifications of the machines priced for the index, and to examine the way quality change was actually handled in the WPI. For the interval of our study (1960–72),

[10]The interpretation and treatment of company effects in hedonic regressions is a perplexing problem for which there is not straightforward solution. Dhrymes (1971, p. 116) first noted such effects, though the explanation he gave for them is unconvincing. Dhrymes asserted that in using hedonic quality adjustments "one ought to take into account the division of the market." Similarly, Ohta–Griliches (1976, p. 39) state that under certain conditions company effects "should be allowed for in the construction of hedonic price indexes." However, aside from noting that company or brand effects exist, and raising the possibility that they *may* pose problems, neither author indicates precisely how company effects do influence hedonic price indexes, or how they should be handled when hedonic results are used for making quality adjustments.

[11]Note that Ohta–Griliches (1976) concluded that the equivalent "make" effects for autos were associated with omitted quality characteristics precisely on the grounds that company effects in their regressions were stable and persisted over a long period.

we retraced the history of the WPI refrigerator-freezer index. We consulted the WPI historical records on price and specification changes, plus records of the methods used for handling each observed quality change. We did this for every price comparison for every month in the period 1960–1972. In some instances, documentation ambiguity forced us to make judgments about quantities of some characteristics; however, this is not a major source of error, because the characteristics of the models preceding and succeeding the questionable one were known, and the model designations and numbers were the same, or closely similar.[12]

During the 1960–72 period, there were 76 reported instances of changes in specifications of refrigerator-freezers priced for the index. In 46 of the 76 cases, the BLS commodity specialist decided that quality changes were minor, and prices of the new and old machines were compared directly. We applied an explicit hedonic quality adjustment to 20 of the 46 cases the BLS originally handled by direct comparison of prices. No quality adjustment was made in the other 26 cases (because the WPI substitution involved no change in the characteristics included in our hedonic functions).

The remaining 30 of the 76 observed instances of quality change were judged by the BLS commodity specialist to be "major" changes. Standard BLS procedure for those cases is to assume that the whole of the difference between prices of two refrigerators in adjacent months was caused by quality change, and there was no "pure" price change. This procedure, too, introduces potential error into the index. We applied explicit quality adjustments to 25 of the 30 "major quality change" cases.

Thus, there were 31 reported changes (26 "minor" changes and 5 originally classified as "major") where we did *not* apply a specific quality adjustment. In each of these 31 cases, the substitution which occurred involved two refrigerators which were adjudged equal quality by application of the hedonic technique (that is, there were no reported changes on the characteristics which were retained in the final versions of our hedonic functions). In a number of these cases, the only change that could be detected was the model number. One change involved an alteration in the marketing relationship, and another the inclusion of a service contract in the price. We let the BLS treatment of these last two stand. The five substitutions which the commodity specialist decided were "major" changes, but for which the hedonic function indicated no measurable quality change, indicate that the WPI "pricing specification" for this product contains a larger number of characteristics than does the hedonic function.

It has often been presumed that the quality problem in price indexes arises mainly because prices of goods of different quality are compared directly, without quality adjustment, and that, moreover, hedonic quality adjustments applied to such cases would cause substantial revisions. It is noteworthy, therefore, that the data from the WPI refrigerator-freezer index suggest that this "classic" example of quality error is by no means the predominant one: only 20 out of 76 reported substitutions conform to this pattern. Substitutions handled by assuming there is

[12]Refrigerator manufacturers usually make up their model designations according to a code that identifies salient features of the machine.

quality change but no price change arise frequently in the refrigerator index, and possibly contribute as much, if not more, to the overall index quality error.[13]

With three final sets of regression coefficients at hand (those for 1963–65, for 1969–72, and for 1970–72), many patterns of adjustment are possible. Indexes were computed using the 1969–72 and 1970–72 pooled regression coefficients for the entire period. Because we are least confident in the predictions of the 1963–65 regression (particularly when extrapolated beyond the sample period), coefficients from this regression were not used for adjustments after 1969. Six patterns of coefficient sets were selected for adjusting the WPI price quotes and are set forth in Table 4; these produced six different hedonic-adjusted WPI's, annual averages of which are detailed in Table 5.

TABLE 4

IDENTIFICATION OF POOLED REGRESSION COEFFICIENTS USED FOR QUALITY ADJUSTMENT IN THE SEVERAL INDEXES OF TABLE 5

Time Period	A	B	C	D	E	F
1960–62	I	I	I	I	II	III
1963–65	I	I	I	I	II	III
1966–68	I	I	II	III	II	III
1969	II	I	II	III	II	III
1970–72	II	III	II	III	II	III

The regression coefficients are from the three regressions in Table 2, according to the following codes:

I = coefficients from 1963–65 regression used to adjust the index.
II = coefficients from 1969–72 regression used to adjust the index.
III = coefficients from 1970–72 regression used to adjust the index.

Also in Table 5 is our comparison index, which we refer to as the "standardized" WPI. Most of the differences (which are small, in any case) between our "standardized" WPI and the published WPI refrigerator-freezer index stem from the time of introducing corrections (and in some cases, price and specification changes) into the index, though in three instances (out of the 156 monthly computations over the period of our study) we were unable to reproduce the WPI price relatives exactly, and used instead our most plausible reconstruction of WPI procedures. We wish to emphasize that our "standardized" WPI is not necessarily superior to the published index; we computed it solely because we needed an index which would differ from our hedonic-adjusted indexes *only* in the method of handling quality changes.[14]

The first point to be made about the indexes of Table 5 is that the pattern of coefficients used in making the quality adjustment has little impact: All six

[13]There is a general presumption that these errors tend to bias the index downward, though little firm data on the question exists. See Triplett (1971, pp. 185–187).

[14]After the computations for this paper were completed the WPI refrigerator-freezer index for 1970–72 was revised.

TABLE 5

PRICE INDEXES FOR REFRIGERATOR-FREEZERS—ANNUAL AVERAGES (1960 = 100)

		Hedonic Adjusted Indexes[b]					
	WPI[a]	A	B	C	D	E	F
1960	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1961	94.10	97.14	97.14	97.14	97.14	97.12	96.07
1962	90.81	93.07	93.07	93.07	93.07	93.10	92.10
1963	84.81	84.94	84.94	84.94	84.94	85.22	84.26
1964	81.95	78.60	78.60	78.60	78.60	78.83	78.53
1965	80.99	75.74	75.74	75.74	75.74	75.96	76.15
1966	79.47	73.17	73.17	73.29	73.57	73.47	73.92
1967	79.07	72.85	72.85	73.00	73.11	73.19	73.45
1968	81.77	74.25	74.25	75.33	74.47	75.52	74.82
1969	83.05	72.43	72.36	74.68	74.48	74.86	74.84
1970	83.77	74.43	74.15	76.74	76.47	76.93	76.83
1971	85.46	77.45	76.96	79.85	79.37	80.05	79.75
1972	83.26	75.08	75.63	77.40	77.99	77.60	78.36

[a]Differs somewhat from the published WPI (see text).

[b]Calculated using the hedonic regression coefficients presented in Table 2 to adjust the basic data, according to the scheme detailed in Table 4.

alternative indexes agree quite closely. We judged the adjustment pattern used in indexes "C" and "D" to be preferable (especially with respect to bridging the gap where we have no regressions), and hereafter designate these as our "preferred" indexes.

Comparing these indexes to our "standardized" WPI, we find that the WPI fell more than the hedonic index in 1960–61,[15] and was again downward biased during the period of rising prices from 1969–72. On the other hand, the hedonic-adjusted index shows much the larger drop over the 1963–65 interval, and fell between 1965–69, a period in which the WPI index was rising. Taking the entire thirteen year period 1960–72, the net effect is one of upward quality bias, as applying hedonic quality adjustments to the WPI caused it to fall 5 to 8 index points more than it did using conventional quality adjustments.

The pattern of quality errors suggested by the hedonic results is interesting. The error is uniform neither in sign nor in magnitude. Though the net long-term result is consistent with the usual presumption about quality error (that it biases price indexes upward), the result does not hold for all sub-periods. For example, these indexes suggest that the beginnings of the current inflation in appliance prices (around 1965–69) were perhaps overstated; but some of the subsequent and more recent inflation was masked by quality error in the indexes, so that hedonic-adjusted WPI's show *greater* inflation during 1969–72 than did the published index.

[15]The use of annual averages obscures the fact that all of the indexes dropped nearly twelve percent during 1960. Our quality adjusted indexes are not systematically different from the published WPI in this regard, however.

IV. Alternative Methods for Using Hedonic Results: A Methodological Digression

Previous studies which have employed the hedonic technique to obtain quality-adjusted price indexes have usually estimated an index number directly from a regression. Our method gives (it turns out) strikingly different results. The present section explores this matter, but the new output and output per employee hour measures in Section V are based only on the price indexes we have already presented in Table 5.

To compare alternative methods, we computed a number of regression-estimated price indexes, similar to those commonly encountered in the hedonic literature (see Griliches, 1971). One type was based on a set of adjacent-year regressions in which a single time dummy variable picked up price change between the two years. Adjacent-year regressions were run with and without the company effects which were so important in the single-year regressions, and in those of Tables 2 and 3.

In addition, indexes were computed from regressions which included all seven years data in a single regression; in these multi-year pooled regressions, a series of time dummy variables estimated the yearly price indexes. In one, we constrained the coefficients on the quality characteristics to be the same for all seven years. In a second, we introduced slope dummy variables, in order to permit characteristics prices to differ between 1963–65 and 1969–72. The third multi-year pooled regression is similar to the second, except that slope dummies were entered via a stepwise regression, and we retained only those whose inclusion reduced the standard error of the residual.[16]

To conserve space, we present in Table 6 only the percentage changes from these various indexes, grouped over selected time periods. The indexes estimated directly from a regression (hereinafter referred to as "regression indexes") are compared with percentage changes in the CPI and WPI refrigerator-freezer components and with our hedonic-adjusted WPI indexes (from Table 5).

Differences among the five regression indexes are generally smaller than the differences between those indexes and the hedonic-adjusted WPI's. The five regression indexes indicate a drop in quality-adjusted refrigerator prices of around 20–27 percent between 1963 and 1965, and in the range of 18 to 28 percent for the 1963–72 period as a whole. These are several multiples of the decrease in quality-adjusted refrigerator prices one gets from applying hedonic quality adjustments to individual WPI price quotations (the last two columns of Table 6).

Comparing shorter periods, we conclude that the regression indexes produce far larger estimates of upward quality bias, when quality error pushed the indexes upward (1963–69), and a considerably larger negative quality error when the error goes the other way (1969–72). The regression indexes, in other words, give more extreme estimates of the quality error in price indexes than we get from the hedonic-adjusted WPI's.

[16]Dummy variables for company effects were not included in multi-year regressions, since they were considered to be too unstable across years to be useful in an aggregated form, while if they were included for each year it would be impossible to separate out the year dummies that we are seeking. Also the four additional variables for the 1970–72 period were not included.

TABLE 6

COMPARISON OF PERCENTAGE CHANGES IN REFRIGERATOR PRICE INDEXES COMPUTED FROM VARYING DATA SOURCES AND BY DIFFERING METHODS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
			Hedonic Indexes						
			From Adjacent-Year Regressions		From Pooled Multi-Year Regressions			Hedonic-Adjusted WPI[b]	
Years	CPI	WPI[a]	With Company Effects	Without Company Effects	With Slope Effects	With Stepwise Slope Effects	No Slope Effects	C	D
1963–65	−4.9	−4.5	−27.0	−21.3	−21.2	−21.0	−20.3	−10.8	−10.8
1965–69	−1.1	2.5	−11.0	− 8.5	− 2.4	− 7.9	−11.6	− 1.4	− 1.7
1969–72	−4.8	0.0	10.6	9.6	6.2	6.1	6.8	3.6	4.7
1963–72	−1.4	−1.8	−28.1	−21.1	−18.3	−22.8	−24.7	− 8.9	− 8.2

[a]See footnote a, Table 5.
[b]Indexes C and D from Table 5.

The regression indexes amount to quality adjusted *retail list* price indexes; our hedonic-adjusted WPI's are based on quality-adjusted *transactions* prices, collected at the *manufacturer*'s level. There are thus four factors intervening between the two sets of hedonic indexes: (1) differences between movements in retail and wholesale prices; (2) differences between movements in transactions and list prices, (3) possible divergence between average price change in the small sample of refrigerators priced for the WPI and in the much larger number of machines included in the regressions, and (4) differences caused solely by the computational method of applying the hedonic technique.

We first consider the final factor (computation methods). In a semi-log adjacent year regression, the price index is obtained from the exponential of the estimated coefficient of the time variable. Applying the formula for a regression coefficient, we have:

$$(1)\quad I_{t,s} = \exp(b_{t,s}) = \left[\prod_{i=1}^{n} (P_i^t)^{1/n} \Big/ \prod_{i=1}^{m} (P_i^s)^{1/m}\right] \div \exp\left[\sum_j b_j\left(\sum_{i=1}^{n} X_{ij}^t/n - \sum_{i=1}^{m} X_{ij}^s/m\right)\right]$$

(where t and s are pricing periods, i indicates an observation and j a refrigerator characteristic). In words, the regression index is equal to the ratio of the geometric means of prices in the two years, divided by a hedonic quality adjustment which imputes a value for the mean changes in characteristics between the two periods. A similar formula is implied by a multi-year time dummy regression.

Our "hedonic-adjusted WPI" computations (Table 5) link quality adjustments to individual WPI prices and therefore to the WPI index formula. The WPI *refrigerator* price index is simply the ratio of equally-weighted mean prices (i.e., $\bar{P}^t/\bar{P}^s$). Thus our hedonic-adjusted WPI price index becomes (retaining the same notation used in equation 1):

$$I_{t,s} = \sum_i P_i^t \Big/ \sum_i P_i^s \exp\left[\sum_j b_j (X_{ij}^t - X_{ij}^s)\right] \tag{2}$$

This can be rewritten to be more easily compared with equation (1):

$$I_{t,s} = \left[\sum_i P_i^t \Big/ \sum_i P_i^s\right] \div \left[\sum_i W_i^s \exp \sum_j b_j (X_{ij}^t - X_{ij}^s)\right] \tag{2a}$$

where

$$W_i^s = P_i^s \Big/ \sum_i P_i^s.$$

Note that in (2) and (2a), but not in (1), the number of observations is the same in both periods.

Equation (2a) differs in several respects from equation (1). To evaluate these differences we recomputed our hedonic-adjusted WPI, using equation (1) and coefficients appropriate to our index "C" (Table 5). Over the June 1963 to June 1972 period (for computational reasons we compared mid-year points, rather than the annual averages of Table 5), the recomputed index fell about 2 percentage points more than did index "C". Thus we conclude that the formula accounts for part of the difference between the regression indexes and the hedonic-adjusted WPI's, but probably only around 10 percent of the discrepancy.

Griliches (see the "Introduction" to Griliches, ed., 1971) has raised some econometric difficulties with indexes estimated directly from a regression, including the requirement that the various yearly samples must have, in effect, the "same" observations in terms of the omitted quality characteristics. There are no operational solutions to these problems. On Griliches' argument, the error would affect the regression indexes, but not our hedonic-adjusted WPI's. This could account for part of the discrepancy.

We next consider the nature of the samples. The WPI sample overweights smaller refrigerators (because it prices the single largest-selling refrigerator model from each manufacturer, and these turn out to be relatively small machines). On the other hand, the regression indexes overweight larger refrigerators because there is a larger variety of them, with smaller sales for each individual model. Because estimated implicit prices for refrigerator characteristics have fallen over the period studied (see Table 2), we conclude that larger, higher quality refrigerators have fallen in price relative to the smaller ones, which implies that the WPI is upward-biased and the regression indexes downward biased because of the composition of their respective samples. Our data are insufficient to form an estimate of the size of the sampling biases, but their probable directions suggest that sample composition accounts for some of the 1960–72 discrepancy between the regression indexes and the hedonic-adjusted WPI's. Sampling considerations do not, however, seem to account for the more extreme swings in the regression indexes.

Finally, it is possible that part of the difference between the regression indexes (which are quality-adjusted retail list price indexes) and our hedonic-adjusted WPI's represents compression of retail and distributors margins over the period and a fall of retail list prices relative to true transactions prices (i.e., reduction of retail discounts). The published CPI and WPI refrigerator indexes move closely together over this period (Table 6); but hedonic adjustment of the WPI produces an index which differs from the published WPI, and use of similar methods on CPI price quotations could also lead to revision of the retail price series. We lack data to explore this question further.

Comparisons of hedonic price indexes computed directly from a regression with indexes such as the published WPI or CPI may reflect differences in computational methods as well as different data sets. This point has been overlooked in almost all previous hedonic studies: The investigator has typically estimated his alternative price index directly from a regression (almost invariably one based on list prices), and compared it directly with a component of the published indexes—without bothering very much with the question of whether the comparison was a legitimate one. Differences between index numbers computed from hedonic regressions and published index components have been taken as providing purely or primarily estimates of the quality error in the published indexes.[17] They may reflect that, and other things besides.

V. The Quality Error in Measures of Output, and Output Per Employee Hour

Estimation of quality error in the refrigerator price indexes is but a necessary preliminary to our objective—assessing the effect of unmeasured quality change on measures of output and output per employee hour.

The output figures with which we are concerned are derived by the BLS from Census value of shipments data for the appliance industry, using GNP implicit price deflators. The deflators, in turn, are based on WPI indexes, and (in the case of appliance indexes) parallel closely movements in the corresponding WPI series. Thus, the quality-adjusted price indexes presented in Section III—which were created by applying hedonic quality adjustments to the WPI—can be employed as deflators to correct the output series for the value of quality change.

Our original goal was to estimate the quality error in output measures for the major household appliances industry. Our quality adjusted price indexes, however, cover only a portion of that industry. With them we can produce new output measures for the refrigeration equipment industry. Application of adjustments from the refrigerator study to the entire appliance industry can be made on the assumption that unmeasured quality change in the data for other appliance products is equal to the quality error which we have estimated for refrigerator-freezers. An alternative assumption is that quality error has infested only the data for the refrigeration equipment subindustry, with no error present in the indexes for other appliance products.[18] To conserve space, we have presented indexes based only on the former assumption. To compute indexes on the alternative

[17] A significant exception to this statement is the original Griliches (1961) hedonic article, which does examine similar questions.

[18] Making assumptions about the degree of quality error in the indexes for other appliance products is not equivalent to assuming anything about the extent of quality change for those products.

assumption, the correction ratio (see below) should be weighted by the share of refrigerators in the major household appliance industry (about 35 percent, on average, of total employee hours).

We produced new quality-adjusted output measures according to the following procedure. Note, first, that a deflated output index results from deflation of a value of shipments series by a price index,

$$Q = VS/P.$$

The product of new quality-corrected price and output indexes (which we designate P^* and Q^*, respectively) must also equal the value of shipments, which implies that

$$Q^* = (P/P^*)Q.$$

Thus, we arrive at the corrected output measure by multiplying the original output index for the refrigerator industry (or the major appliance industry, on the assumption noted above) by the ratio of the original WPI refrigerator index to our new hedonic-adjusted WPI indexes (from Table 5). The new measure of output per employee hour is simply Q^* divided by the all employee hours figure for the refrigerator industry (or the major appliance industry, where appropriate).[19]

Tables 7 and 8 present (respectively) our adjusted annual series for output, and output per employee hour, for both refrigeration equipment and the major household appliances industry.[20] For each case we show the original BLS indexes, and the result of recalculation, using our preferred price indexes (those in Table 5 designated "C" and "D").[21]

Looking first at the entire period 1960–72, our new output and output per employee hour figures rise more than did the original BLS figures. This is exactly what we expect, given that our hedonic-adjusted WPI's (Table 5) rose less, over the full period, than did the official WPI—which implies understatement of the deflated output measures.

[19]The resulting indexes are not strictly commensurate with previously published BLS output and output per employee hour series. Although the published measures are based on deflated value of shipments, they are benchmarked (in census years, using a combination of Census unit values and Wholesale Price Indexes). Ignoring this complication has simplified our computational burden considerably. Computation of the BLS appliance output series is described in the unpublished "Technical Appendix" to Henneberger and Gale (1970).

[20]The output (and output per employee hour) measures refer to establishments classified (by the Census Bureau) in the refrigerator and major appliance *industries*. These figures may therefore differ from the output of refrigerators, or major appliances, produced in the economy because (a) some appliance industry establishments produce some non-appliance output, and (b) establishments classified elsewhere produce some appliances. Output of the refrigerator equipment industry dropped precipitously in 1971 (see Table 8). We infer, from comparing product shipments and industry shipments (SIC 3632) for the 1967–72 Census of Manufacturers, that the drop in industry output (and employment) figures between 1970 and 1971 probably reflects reclassification of some establishments producing refrigerators out of SIC 3632 (and possibly out of the appliance industry).

[21]We computed new output and output per employee measures using all six of the hedonic-corrected WPI's from Table 5. Because the alternative price indexes track closely, so do the new output measures. As an example, consider the average annual rates of change, 1960–1972, in the measure of output per employee hour in refrigeration equipment: The range produced by use of our alternative indexes "A" through "F" from Table 5, extends from 7.30 percent (index "F") to 7.76 percent (indexes "A" and "B"). Our preferred indexes "C" and "D" record 7.41 and 7.43 percent, in the middle of the range of alternative estimates. In contrast, the original BLS measure was 6.35 percent per year.

TABLE 7

INDEXES OF OUTPUT, 1960–72
(1960 = 100)

	Refrigeration Equipment			Major Household Appliances		
		Adjusted			Adjusted	
	BLS	C	D	BLS	C	D
1960	100.0	100.0	100.0	100.0	100.0	100.0
1961	97.0	94.0	94.0	98.9	95.8	95.8
1962	111.6	108.9	108.9	110.9	108.2	108.2
1963	128.0	127.8	127.8	123.0	122.9	122.9
1964	147.7	154.0	154.0	136.6	142.5	142.5
1965	163.4	174.7	174.7	148.2	158.4	158.4
1966	177.6	192.5	191.8	156.0	169.2	168.5
1967	186.9	202.5	202.2	160.0	173.3	173.0
1968	205.6	223.2	225.8	176.6	191.7	194.0
1969	197.9	220.1	220.7	176.0	195.7	196.3
1970	183.2	200.0	200.7	169.0	184.4	185.1
1971	145.8	156.0	157.0	159.2	170.4	171.4
1972	158.1	170.1	168.8	179.8	193.5	192.0

TABLE 8

INDEXES OF OUTPUT PER EMPLOYEE HOUR, 1960–72
(1960 = 100)

	Refrigeration Equipment			Major Household Appliances		
		Adjusted			Adjusted	
	BLS	C	D	BLS	C	D
1960	100.0	100.0	100.0	100.0	100.0	100.0
1961	106.5	103.2	103.2	106.5	103.2	103.2
1962	115.4	112.6	112.6	115.8	113.0	113.0
1963	135.6	135.3	135.3	132.3	132.1	132.1
1964	144.6	150.7	150.7	137.9	143.7	143.7
1965	149.3	159.7	159.7	142.1	151.9	151.9
1966	151.4	164.1	163.5	142.5	154.6	154.0
1967	165.0	178.8	178.5	150.8	163.4	163.1
1968	172.4	187.2	189.3	158.5	172.1	174.1
1969	179.8	200.0	200.5	163.8	186.2	182.6
1970	173.0	188.8	189.5	159.6	174.2	174.8
1971	209.7	224.4	225.8	181.4	194.2	195.4
1972	226.7	243.8	242.0	197.1	212.1	210.5

But just as quality error in the price indexes was in some periods negative, so the adjustment in the output per employee hour measures raises them in some periods and lowers them in others. As a generalization, our new output measures rise more when output is rising (1961–66, for example) and fall more when output fell (1960–61 and 1969–71) than did the original series. In fact, the size of the quality error we have estimated in the output measures is positively correlated with *changes* in output.[22] Thus, we arrive at the striking conclusion that quality error in the refrigerator indexes is cyclical—at least for the period investigated—and that correction by hedonic methods produces larger cyclical swings in output than is revealed by the published series. We emphasize that we are not making a business-cycle generalization here, as we have too few cyclical patterns: Our results apply only to output swings over the 1960–72 period.

A similar pattern can be discerned in the output per employee hour measures. There is a positive correlation between the increase in output per hour and the adjustment produced in the output per hour measures by our new indexes.

Thus, we conclude that using hedonic methods to correct output indexes for quality change raises somewhat the trend of output per employee hour. But it also increases measured swings in output in this industry, and imparts more year-to-year variability, as well as a more pronounced cyclical pattern, into the output per employee measures.

An important economic issue in recent years concerns the supposed slackening of the historical rate of growth in output per employee hour in the mid-1960s, and whether this is a cyclical or a trend phenomenon. Given the cyclical pattern and the degree of year-to-year variability in our new indexes, it is impossible, without more data, to determine conclusively whether there has been a break in the trend of growth in output per employee hour in the appliance industry.

References

Box, G. E. P. and D. R. Cox, "An Analysis of Transformations," *Journal of the Royal Statistical Society*, Series B (1964, No. 2), pp. 211–252.

Burstein, M. L. (1960), "The Demand for Household Refrigeration in the United States," Chapter III (pp. 99–145) of A. C. Harberger, editor, *The Demand for Durable Goods* (Chicago, University of Chicago Press, 1960).

——— (1961), "Measurement of Quality Changes in Consumer Durables," *The Manchester School* (Vol. 29, September, 1961), pp. 267–279.

Dhrymes, Phoebus (1967), "On the Measurement of Price and Quality Changes in Some Consumer Capital Goods," *American Economic Review* (Vol. LVII, May, 1967), pp. 501–518.

——— (1971), "Price and Quality Changes in Consumer Capital Goods: An Empirical Study," in Griliches (1971).

Dzick, E. M. ed. for the National Appliance and Radio–TV Dealers Association, *1972 Home Appliance Blue Book* (Madison Wisconsin, Select Publishing Co., 1972).

Gordon, Robert J., "Measurement Bias in Price Indexes for Capital Goods," *Review of Income and Wealth* (Vol. 17, No. 2, 1971), pp. 121–174.

Griliches, Zvi (1961), "Hedonic Price Indexes for Automobiles: An Econometric Analysis of Quality Change," in *The Price Statistics of the Federal Government*, National Bureau of Economic Research, Number 73, General Series, 1961, reprinted in Griliches (1971).

——— (1971), editor, *Price Indexes and Quality Change: Studies in New Methods of Measurement* (Cambridge, Mass., Harvard University Press, 1971).

Henneberger, John E. and Hazen F. Gale, "Productivity in the Major Household Appliance Industry," *Monthly Labor Review* (Vol. 93, September, 1970), pp. 39–42.

Lancaster, K., *Consumer Demand: A New Approach* (Columbia Studies in Economics, No. 5), New York and London, Columbia University Press (1971).

Lucas, Robert E. B., "Hedonic Price Functions," *Economic Inquiry* (Vol. 13, No. 2, June, 1975), pp. 157–178.

[22]In the notation established above, the correlation coefficient between percent changes in (P^*/P) and percent changes in Q^* for refrigeration equipment was 0.77 using index "C" to make the adjustments.

Muellbauer, John, "Household Production Theory, Quality, and the Hedonic Technique," *American Economic Review*, Vol. LXIV, December, 1974, pp. 977–994.

Ohta, Makoto and Zvi Griliches, "Automobile Prices Revisited: Extensions of the Hedonic Hypothesis," in Nestor E. Terleckyj, ed., *Household Production and Consumption*, National Bureau of Economic Research, Studies in Research in Income and Wealth, Vol. 40 (1976).

Pollak, Robert A., "The Theory of the Cost of Living Index," BLS Working Paper No. 11, Research Division, Office of Prices and Living Conditions, U.S. Bureau of Labor Statistics, June, 1971.

Rosen, Sherwin, "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition," *Journal of Political Economy* (Vol. 82, No. 1, 1974), pp. 34–55.

Samuelson, Paul A. and S. Swamy, "Invariant Economic Index Numbers and Canonical Duality: Survey and Synthesis," *American Economic Review*, September, 1974, Vol. LXIV, No. 4, pp. 566–593.

Triplett, Jack E. (1966), "The Measurement of Quality Change," Ph.D. dissertation, University of California, 1966.

——— (1971), "Quality Bias in Price Indexes and New Methods of Quality Measurement," in Griliches (1971).

——— (1976), "Consumer Demand and Characteristics of Consumption Goods," in Nestor E. Terleckyj, ed., *Household Production and Consumption*, National Bureau of Economic Research, Studies in Research in Income and Wealth, Vol. 40 (1976).

——— (1975), "The Measurement of Inflation: A Survey of Research on the Accuracy of Price Indexes," in Paul H. Earl, editor, *Analysis of Inflation*, D.C. Health Company (Lexington Books), 1975.