# TESTING THE 'CAGAN-HALL' AND THE 'HEDONIC' HYPOTHESES

by

J. N. J. Muellbauer

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This paper is circulated for discussion purposes only and its contents should be considered preliminary.

## I. INTRODUCTION

This paper investigates price change, quality change and depreciation behaviour using data from one of the best developed used durable markets in the U.S. The approach used was apparently first suggested by Burstein ( 1 ), actually used with considerable success by Cagan ( 2 ) and formalized and further developed by Hall ( 18 ).

Section II presents some economic theory on input price indices which is made operational for the data on used capital good prices. Section III briefly discusses earlier work. The next three sections present hypotheses tests. It was intended to follow a decision tree approach in nested hypothesis testing in a classical statistical framework. For several reasons this does not emerge quite as elegantly as had been hoped. Section IV investigates aggregation (to be developed in a further paper on empirical tests of capital aggregation). Section V investigates hypotheses on depreciation rates. Section VI investigates the hypothesis that information on performance characteristics can predict quality differences between capital goods as evaluated by the market. Section VII offers some tentative conclusions. Appendix A discusses the methods and calculations with some illustrative prices. Appendix B discusses data sources and problems.

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## II Quality Change and the Theory of Input Price Indices

In an earlier paper, I discussed the theory of input price indices and the treatment therein of quality change ([1] ). In brief , the argument ran as follows.

An input price index is a summary measure of the level of current period input prices, w, relative to base period input prices $\hat{w}$. For example, the Laspeyres and Paasche concepts measure the relative cost under w and $\hat{w}$ of purchasing two given input bundles, the base and current bundles respectively. For a production theoretic ('true') input price index, we seek a more interesting standard of reference than a given input bundle to compare price levels. The analogy with the 'true' cost-of-living index is helpful in this: such an index measures the relative cost of attaining a given reference level of utility under current and base period prices ( [2] ). By analogy, we seek a scalar measure of real output and define as the desired index the relative cost of attaining a given reference level of real output under current and base period input prices.

The most natural procedure for formally presenting such an index is by using the Shephard duality theorem to define a cost function C = C (w; qx; b) which under certain conditions is dual to the production structure implicitly defined by F (qx; v; b) = 0 ( 29 ).

Here w = input price vector

v = input vector

b = quality parameter w.r.t. one or more inputs

x = vector of output proportions

q = level at which x is produced

Taking as reference, the vector of output proportions x to be fixed and a given level $\hat{q}$ of real output ( [3] ), the production theoretic input price index is

$$W = \frac{C\,(w_1 \,\ldots.\, w_{m-1}\,, w_m\,;\ \hat{q}\ x;\ b)}{C\,(\hat{w}_1\,, \ldots.\ \hat{w}_{m-1}\,, \hat{w}_m\,;\ \hat{q}\ x;\ 1)}$$

where b = 1 in the base period.

It is understood that in the case of durable inputs, $v_i$ is the service flow from the ith input and $w_i$ is the rental price of services from the ith input.

In the absence of technical and quality change, the Laspeyres input price index is an upper bound on W ( [4] ), which may be an important reason for being interested in the Laspeyres index. Under quality change, this relationship breaks down in general. Suppose a quality change ( [5] ) takes place in the mth input. A traditional way of dealing with quality change in price index construction has been to adjust the price, $w_m$, of the good in which quality change has taken place. Ideally one would like to be able to adjust the price of the mth input in a SIMPLE way i.e. independently of market conditions (other input prices and the amounts of the various inputs). If quality change were of the type that allowed

$$C(w_1 \ldots w_{m-1}, w_m ; \hat{q}x; b) = C(w_1 \ldots w_{m-1}, w_m^*; \hat{q}x; 1) \quad \text{(II.2)}$$

where $\frac{1}{w_m} \cdot \frac{\partial w_m^*}{\partial b}\Big|_{at\ w_1 \ldots w_m}$ is independent of $v_1 \ldots v_m$ and $w_1 \ldots w_m$, then the above bounding relationship between W and the Laspeyres index would persist if the mth price in the latter were replaced by $w_m^*$. It is shown in ( 26 ) that this simple adjustment is possible if and only if the production structure can be written in the form,

$$F (qx; v_1 \ldots v_{m-1}, h(b).v_m ) = 0. \quad ( [6] ) \quad \text{(II.3)}$$

This implies that the cost function, is

$$C = C(w_1 \ldots w_{m-1}, \frac{w_m}{h(b)} ; qx). \quad \text{(II.4)}$$

Since we can rescale the units of the quality parameter (changing C and F appropriately) we can just as well write b instead of h(b) ( [7] ).

This sort of quality parameterization has another function. If we can assume over a group of inputs that this form characterizes technical differences between them at a point in time, then we can aggregate consistently ( [8] ) and find the efficiency corrected price index for a group of inputs. This can at a later stage be fed into overall input price indices.

We need to assume this form of efficiency difference both between capital services from different ages of the same model, and between capital services from different models of a given age.

Although the relevant concept is capital services rather than the stock concept of capital, rental prices are rarely directly observable. Thus a link needs to be forged for empirical purposes between the prices of the capital goods themselves and the rental prices. Following Hall ( 18 ), we accept the widely made assumption that the price of capital good i of age $\tau$ observed at time t, equals the present value of expected future services:

$$u_{i,t,\tau} = \sum_{s=0}^{s=N-\tau-1} \left(\frac{1}{1+r}\right)^{s} z_{i,t+s,\tau+s} \qquad \text{(II.5.)}$$

where the rate of time discount r is expected to remain the same, $z_{i,t+s,\tau+s}$ is the expected value of services of capital good i of age $\tau$ + s at time t + s and N is the total expected lifetime of the good. We assume that deterioration in the value of capital services takes place independently of the year in which the good was produced and of the year in which services are used. In a context where each capital good is produced in a physically identical model over a run of two or more years (case 1), this allows each good to have its own deterioration structure. Then $z_{i,t+s,\tau+s}$ can be split into three multiplicative factors: on efficiency corrected rental price index $w^{*}_{t+s}$ which depends just on the time at which the service flow takes place, a quality index $\bar{b}_i$ specific to the service flow from capital good i (of a standard age), and a deterioration index $\phi_{i,\tau+s}$ which is independent of t and year of manufacture, t $-\tau$, for capital good i,

$$\text{ie.}\, z_{i,t+s,\tau+s} = w^{*}_{t+s}\ \phi_{i\tau+s}\bar{b}_i \qquad \text{(II.6)}$$

If on the other hand each vintage t $-\tau$ is associated with a different quality of a standard aged good (case 2), we can drop subscript i ([9] ) and replace it by t $-\tau$ . Remembering that we require the deterioration index to be independent of the year of manufacture and of the year of observation we can write,

$$z_{t+s,\tau+s} = w^{*}_{t+s}\ \phi_{\tau+s}\bar{b}_{t-\tau}. \qquad \text{(II.7)}$$

We assume that the real rental price $w^*_{t+s}$ is expected to remain at its present level $w^*_t$. Then in case 1 we have

$$u_{i,t,\tau} = \bar{b}_i \left[ w^*_t \sum_{s=0}^{N-\tau-1} \left(\frac{1}{1+r}\right)^s \phi_{i,\tau+s} \right] \qquad \text{(II.8)}$$

But a natural way to define an index of depreciation $D_{i,\tau}$ for capital good i, is as the ratio of the discounted expected stream of returns remaining, to the discounted expected stream of returns of a standard aged model (the one year old model is taken as standard, ie. $D_{i,1} = 1$).

$$\text{ie.} \quad D_{i,\tau} = \frac{\sum_{s=0}^{N-\tau-1} \left(\frac{1}{1+r}\right)^s \phi_{i,\tau+s}}{\sum_{s=0}^{N-2} \left(\frac{1}{1+r}\right)^s \phi_{i,1+s}} \quad ([\text{ii } 4]) \qquad \text{(II.9)}$$

Thus

$$u_{i,t,\tau} = \left[ w^*_t \right] \left[ \bar{b}_i \sum_{s=0}^{N-2} \left(\frac{1}{1+r}\right)^s \phi_{i,1+s} \right] \left[ D_{i,\tau} \right] \qquad \text{(II.10)}$$

Thus $\quad u_{i,t,\tau} = w^*_t \, D_{i,\tau} \, b_i \qquad \text{(II.11)}$

$$\text{where} \quad b_i = \bar{b}_i \sum_{s=0}^{N-2} \left(\frac{1}{1+r}\right)^s \phi_{i,1+s}$$

We have succeeded in expressing the price of a capital good i of age $\tau$ at time t (which can be observed from used capital good markets) as the multiple of an efficiency corrected price index which depends just on the time of observation t(and which applies to all the models in the group over which aggregation is possible), a depreciation index for capital good i which depends just on its age, and a quality index which applies to the quality of the good measured at a standard age (age = 1 year), which is independent of the year of observation. Given data on the prices of a number of used capital goods of different ages observed at different times, the quality index of one of them is normalized to unity and the prices are explained by model dummies (one less than the number of models), time dummies (number of year s' observations), and age dummies (for each mo el, one less in number than the maximum age observed). Formally the statistical hypothesis is :

$$u_{i,t,\tau} = w^*_t \, D_{i,\tau} \, b_i \, e^{\epsilon_{i,t,\tau}} \qquad \text{(II.12)}$$

A simple illustration of the regression model in matrix form obtained by taking natural logarithms of (II.12) is given in appendix (A). To carry out estimation and hypothesis testing in the framework of the classical linear model, we need to assume that $\epsilon_{i,t,\tau}$ is independently, normally distributed with constant variance ([10]).

In case 2, when a different quality index is associated with each vintage, then (II.7) implies

$$u_{t,\tau} = \bar{b}_{t-\tau}\left[w_t^* \sum_{s=0}^{N-\tau-1}\left(\frac{1}{1+r}\right)^s \phi_{\tau+s}\right] \quad \text{(II.13)}$$

$$= \overset{*}{\omega}_t \, D_\tau \, b_{t-\tau} \quad \text{(II.14)}$$

using the previous argument,

where

$$b_{t-\tau} = \bar{b}^*_{t-\tau}\sum_{s=0}^{N-2}\left(\frac{1}{1+r}\right)^s \phi_{s+2} \quad \text{(II.15)}$$

As Hall (18,19), pointed out, there is an identification problem here: the trends in the three sets of parameters cannot be identified. This is easy to see:

$$\overset{*}{\omega}_t \, D_\tau \, b_{t-\tau} = \left[\overset{*}{\omega}_t \, B^{-t}\right]\left[D_\tau B^{\tau}\right]\left[b_{t-\tau} \, B^{t-\tau}\right]$$

where B is an arbitrary positive constant. To get identification, we need to fix some pair of values or introduce another constraint on either the price indices, the depreciation indices or the quality indices. But in case 1 discussed above where the same model is produced in a run of two or more years, this is precisely what happens and this is why there is no identification problem there. A technique used by Hall in his work on pick-up trucks (18), was to introduce the constraint that $b_{t-\tau}$ is determined by a set of specification variables on the capital good.

One feature of the theory as presented so far is worth pointing out: the multiplicative form of the hypothesis is not something that is added on at the end but is central from the beginning. From (II.2) and (II.4), we note that when efficiency change is capital service augmenting or diminishing, the efficiency corrected rental price

$$w^*_m = \frac{w_m}{b}$$

where we now interpret $b$ as an efficiency index i.e. incorporating the effects both of quality change and deterioration. Thus

$$w'_m = w^*_m . b \quad .$$

The multiplicative form for the explanation of capital good prices thus is implied by the assumption of capital service augmenting quality change and capital service diminishing deterioration (given quality) and the hypothesized relation between service prices and good prices.

We now summarize the assumptions made and bring out some of the implications.

A. 1. The assumption of capital service augmenting or diminishing quality change and deterioration: one type of situation which is specifically excluded is one in which quality change takes the form of reducing the labour requirement per unit of output or deterioration the form of increasing the labour requirement, both of which can result in a scrapping decision for older capital goods which depends on the wage rate. This would mean that the desired independence of the efficiency indices from market conditions would not obtain.

A. 2. It is implicitly assumed that there is a 'reasonable' degree of substitutability between the inputs. In practice, it could happen say that the amount of maintenance (involving labour) that has to be done per time period in order to get <u>any</u> output from the capital good, has a lower limit. Then an increase in the wage rate may suddenly reduce the relative value of the oldest goods to zero since the value of output may become less than the labour cost.

A. 3. The absence of corner solutions was assumed ([11]). This was required in proving the necessity for the particular kind of quality change and deterioration assumed.

A. 4. Factor mobility and perfect markets are implicitly assumed in the construction of the cost function

$$C(w; q\, x)$$

([12]) and in aggregating across models ([13]).
There is probably an advantage in this respect in using prices of used rather than new goods: the reported prices are likely to reflect actual prices more closely (less discounting). Further, the non-competitive element, in particular that caused by advertising pressure for new models, is likely to be less. It is worth noting that one advantage of considering used capital goods separately from new ones, is that buyers' liquidity problems and manufacturers price maintenance in times of recession are likely to affect the used market relatively homogeneously and differently probably than the new market.

A. 5. Constant output composition: the production theoretic input price index $W$ was based on comparison of current with base prices with a fixed reference vector $x$ of output proportions. The fact that $x$ actually changes between base and current periods is irrelevant for the construction of $W$, but is relevant for its interpretation.

Over the periods in which particular capital goods are produced in a run of years without specification change, we need to assume that the output composition (at least of the sector in which the capital good is mainly used) is fairly constant. Otherwise changes in relative valuations, i.e. 'quality', may take place even when the physical specification of the capital good has remained constant. Since the changes in output composition take place over time, testing for this kind of influence is equivalent to testing for time effect/model effect interactions. This takes us back to the statistical specification of the model.

I would like to suggest that time effect/model effect interactions are the chief way in which the hypothesis of independence (zero covariance in the context of the normal distribution) of the disturbance terms) is likely to be violated ([14] ). A method for testing for the absence of such interactions is sketched in appendix A.

A. 6. Consistent aggregation across models is a desirable property because of the amount of information that can then be summarized without significant loss by one efficiency corrected price index. However, this sort of proposition is fairly readily testable ( [15] ).

A. 7. Static expectations on future rental prices and rate of time discount: without this hypothesis we cannot separate the observed price into a price index, quality index and depreciation index in such a neat way. An alternative hypothesis, say that expected rental price depends on a linear combination of this and last period's price, is in principle testable on price data from used capital good markets but I have not actually carried out such a test.

A. 8. Deterioration independent of the year of production (although not necessarily equal across models) is an assumption that may be violated if manufacturers, to cut material costs, build in increasingly fine tolerances (with higher consequent maintenance costs) as time passes in a production run - even though the specification when new remains unchanged.

A. 9. We conclude this section by noting that of the parameters in (II.6) and (II.7) only $\cdot_t^*$

can actually be directly estimated from price data on used capital goods on the above assumtions. The deterioration rates of services and the true **service qualities for a capital good can be extracted** only with knowledge of the rate of time discount and the expected life of the capital good. However, it is clear from (II.9) and (II.15) that if length of lives and deterioration indices are equal for different capital goods then the **stock quality indices are proportional** to the **age corrected service quality indices. This has** interesting implications for production function studies where the concern is with correct measurement of capital service inputs ([16]). Equal deterioration structures and length of lives across models implies equal depreciation structures across models. Thus a test for the latter (which is carried out in Section V) is a test of a necessary condition for the former which adds some additional interest.

III Previous Work

In this section we review very briefly the approach of Cagan and Hall and discuss the methods and some associated problems of the 'hedonic' approach to estimating quality adjusted price indices for new goods.

Cagan's approach was to consider the price of a durable good of age $\tau$ at time t as composed of the three multiplicative elements as explained above; a time effect (implying a price index), a model effect (implying a quality index) and an age effect (implying a depreciation index).

In addition, in order to aid identification, he assumed depreciation to be geometric and equal for models in a 'line' (11). If a model is produced in the same version for two years (or more) or if the changes are so small as to be negligible, the rate of depreciation can then be calculated from taking the ratio for a given year of the price of a used model over the price of the 'same' model aged one year less and averaging such ratios over years for a 'line'. Cagan normalizes the quality of one model in the base year to one. The next vintage's quality index can be calculated from an appropriate average of ratios of prices observed in the same year for the two vintages, standardizing for depreciation. The price index for models traded in a particular year is an average of prices for that year standardized for quality and deterioration.

The method is rather sensitive to the estimates of the rate of deterioration, given Cagan's automobile data in which frequent model changes give few observations on the rates of deterioration. In addition, the formal underlying theory is not made explicit.

It is worth pointing out that Cagan's results for a selected sample of U.S. cars, 1954-1960, show more inflation in his quality adjusted price index than in the C.P.I., New Auto component. This surprising result, very different from that of Griliches (15), has now been partly explained in an unpublished paper for the B.L.S. by J.E Triplett.

Briefly, the decline shown in the C.P.I. New Auto index for 1954-1956 is mostly spurious - caused by changes in the way auto prices were measured ([18]). Indeed for 1956-1960, Cagan's results show slightly less inflation (12.2%) in his quality adjusted price index than in the C.P.I., New Auto component (13.6%).

As Hall ( 18 ) points out, his own paper can in large part be regarded as a formalization and refinement of Cagan's work. It is also the work on which the second half of Section II above is based. Hall studied prices observed in 1961-1967 of Ford and Chevrolet pick-up trucks manufactured between 1955 and 1966.

Among Hall's conclusions, the following may be mentioned:

Hall's quality adjusted price index increases substantially more rapidly than the W.P.I. new motor truck component for 1961-1967 ([19]).

The hypothesis of equal depreciation structures between manufacturers is accepted.

The hypothesis of exponential depreciation is rejected.

The 'hedonic hypothesis' in which quality is, for each brand, constrained to be a function of a set of performance characteristics, is accepted in the framework of a maintained hypothesis which allows each model ([20]) own quality index.

The 'hedonic hypothesis' implies slightly but not significantly higher rates of inflation.

The shadow prices of the performance characteristics are completely different between manufacturers.

Since my approach is founded on Hall's work, more general discussion of this approach is left to Section VII where an attempt at some evaluation of alternatives is made.

This seems a good place to turn briefly to the literature on the hedonic method applied to prices of new goods. There is no point is attempting a survey: that has been done by Griliches ( 16 ) and, emphasizing the empirical aspects, by Triplett in an unpublished paper for the B.L.S.

One can distinguish between three methods for obtaining quality adjusted price indices. The first is a time series/cross-section method in which the prices are regressed on the performance characteristics, whose parameters are constrained to be constant across time ([21]), and on time dummy variables which stand for year of observation. The parameters of the time dummies measure price levels in the different years, other things (i.e. quality) being equal. One criticism which can be made of this technique is that the 'real' shadow prices may not remain constant over time ([22]).

The second method which has been used, meets this possible criticism to some extent. In this method, adjacent year regressions are performed, the parameter of the one time dummy measuring the relative change in price level. These relative changes are then linked into an index number series. Griliches has argued that both these methods suffer from a common defect: that they are very sensitive to the vagaries of sample selection. The reason he gives is quite straightforward: if, for example, models are present in the sample one year (but not the previous year), whose prices exceed those predicted on the basis of their performance characteristics, the time dummy will pick up a spurious positive effect, giving an overestimate of the price index for that year.

Both the defects of these approaches, Griliches argues, can be overcome by a third method in which the shadow prices of the performance characteristics are estimated from separate cross-sections for each year. These shadow prices are then applied to the performance characteristics of a given representative model to calculate a time series. Cowling and Cubbin (4), for British cars, and others, e.g. Fettig(7,8) construct an index series in which the reference levels of the characteristics are chain-linked, i.e. held constant only over adjacent years. Griliches and others have suggested that, further, the observations be weighted using market share information when available. The intuitive reason given for this is that models with small sales and unrepresentative relationships between prices and performance characteristics should not contribute as much to the estimation of the shadow prices as larger selling models.

This last suggestion conforms to my own methodological prejudices only if there are grounds for believing that the parameters (i.e. shadow prices) are the same across the whole market and that the variance for each untransformed equation is inversely proportional to the square of sales (where the observations are to be weighted by sales). Now it is not altogether unreasonable to suppose that less popular models may exhibit a higher unexplained variance. However, it seems to me that even IF the slope parameters are identical across models, the above transformation is sub-optimal. It is likely that, for less popular models, the price will exceed the predicted price based on the shadow prices of the characteristics. In other words, the problem is not just one of heteroscedasticity, but also one of non-zero covariances: there is likely to be positive correlation between the disturbance terms for the less popular models. This suggests that a more complicated generalized least squares procedure be used: either one where some a priori assumptions are made about the relevant correlation coefficients, or an iterative procedure suggested by Zellner ( 36 ).

However, it seems preferable to respecify the equations directly instead of doing it indirectly through respecifying the structure assumed for the disturbances. This could be done by introducing dummy variables or allowing some or all of the shadow prices to be different for different parts of the market. It is true that finding a sensible disaggregation involves some work, especially since too much disaggregation raises serious problems of inadequate degrees of freedom and multi-collinearity. If these problems permit none or very little disaggregation, one may be forced to reconsider the desirability of Griliches' objective of allowing the shadow prices freedom to vary over time. Imposing unreasonable aggregation cross-sectionally at each point in time, may be too high a price to pay for the privilege of disaggregation over time. Thus if there is an index number problem (consistent aggregation not holding) it should be faced squarely: sales data instead of being used to weight the observations from which one set of shadow prices is estimated, should be used to construct an index number as a weighted mean of price indices for each of the different segments of the market.

Dhrymes ( 6 ) performed some cross-sectional aggregation tests on a sample of new car prices. His intent was in part to use this as a test of the hedonic hypothesis. He concludes ( 6 ) p.505, that he cannot accept the hypothesis that the price behaviour for the three main car manufacturers is the same ([23]). He also investigated new refrigerator prices using time series/cross-section data ([24]): for only two of six brands, could the hypothesis of the same price behaviour across brands be accepted.

Apart from Hall's test of the hedonic hypothesis which is based on a small set of data, the other tests have been only indirect - byproducts of other pursuits. Of these it is worth mentioning Cowling and Cubbin ( 4 ) and Cowling and Rayner ( 5 ) who used quality adjusted price indices for cars and U.K. tractors respectively to help explain market shares. In the former paper, it is suggested that there is an adjustment process in the new car market. Buyers learn over time: thus if the price of a car is higher than 'warranted' by its performance characteristics, its market share is likely to fall. Indeed, Cowling and Cubbin find that the difference between the actual and the predicted price is significantly related to changes in market shares in the anticipated direction ([25]).

To conclude this section, we examine the work of Fettig ( 7 ), ( 8 ) on the U.S. new tractor market 1950-1962 since this will be relevant for the remainder of this paper. Fettig uses the prices of 'stripped' tractors: he reduces the list prices by the prices of the various attachments ([26]). His indices therefore apply to tractors as sold, only if the prices of attachments behave similarly to those of the basic tractors. Fettig uses each of the three methods mentioned above. Some of his results for a semi-logarithmic specification are summarised below.

Table 1

Comparison of Price Indices for New Farm Tractors

(1960=100)

| | 1 | 2 | 3 | 3(a) | 3(b) | WPI |
|---|---|---|---|---|---|---|
| 1954 | 88 | 90 | 89 | 86 | 94 | 83.1 |
| 1955 | 86 | 87 | 85 | 82 | 89 | 82.6 |
| 1956 | 91 | 91 | 90 | 87 | 93 | 85.8 |
| 1957 | 93 | 93 | 92 | 90 | 94 | 90.8 |
| 1958 | 102 | 102 | 102 | 98 | 103 | 94.7 |
| 1959 | 101 | 100 | 100 | 98 | 101 | 98.4 |
| 1960 | 100 | 100 | 100 | 100 | 100 | 100.0 |
| 1961 | 100 | 102 | 103 | 104 | 102 | 102.1 |
| 1962 | 101 | 102 | 103 | 106 | 102 | 104.1 |

Columns 3, 3(a), 3(b) come from Fettig ( 7 ), table 15, p.50.

Columns 1, 2 come from Fettig ( 7 ), table 20, p.57.

'WPI' is the Farm and Garden Tractor component (code 11.11) of the Wholesale Price Index from BLS annual bulletins.

Column 1 corresponds to method 1 as explained above, pooled regression with time dummies. Column 2 was constructed with the adjacent year regression method (method 2). Column 3 corresponds to the single year regression method giving a chain linked index holding adjacent year average specification weights constant. Columns 3(a) and 3(b) are constructed on the basis of fixed average specifications, those of 1954 and 1960 respectively. The last column gives the WPI Farm and Garden Tractor component.

One interesting feature of Fettig's results is the similarity in the quality adjusted price indices in columns 1 to 3. If this is also true of the tractor market for more recent years, it has, as we shall see, significant repercussions on the validity of the test of the hedonic hypothesis proposed in section VI below. However, if method 3 is used with fixed specification weights instead of chained weights, the results differ substantially. Using 1954 weights over 1954-1962 there is 24% inflation, the 1960 specification weights imply only 9% inflation, while the chained weights methods gives 16% inflation. This sensitivity of the single year regression method to the weights, suggests that although the specification of two tractors may remain unchanged for 2 or 3 years, the measure of relative quality implied by changing relative shadow prices may change considerably. We shall be returning to this issue in section VII.

Fettig finds that only PTO horse power and type of fuel contribute much in explanatory power in his single year regressions. There seems to be some evidence of a decline in the shadow price of horse power and in the price differential attributable to having a diesel engine. However this depends on the mathematical form of the hypothesized price - characteristics relations ([27]). Fettig does not present any results for a multiplicative form so that his detailed conclusions on shadow prices are not comparable to those made in section VI below.

## IV Testing for Aggregation

To construct our maintained hypothesis, we divide the observations into six groups: size categories - large, medium and small, and fuel categories - diesel and gasoline powered. 'Large' means that the h.p. measured at the power take-off is 60 h.p. or over, 'medium' means a P.T.O. h.p. between 40.00 and 59.99 h.p., 'small' means a P.T.O. h.p. under 40.00. We allow each model (all models in the sample are produced in a run of two or more years) its own depreciation structure and quality index. We hypothesize that each group has its own efficiency adjusted price index, i.e. that aggregation is possible across the models in each group. The calculations are briefly described in Appendix A.

Within this framework, we test several hypotheses of aggregation across groups. Table 2 presents efficiency corrected price indices for 1958-1969, sums of squared residuals, number of observations and number of parameters estimated, for each group separately and for some of the plausible aggregations across groups. See also Charts 1, 2, 3.

Given the model, including statistical assumptions, of p. 5, 6, then the vector y of n observations on log $w_{i,t,\tau}$ for particular set of models has the following properties under a maintained hypothesis $\Omega$ :

> $E(y) = \eta_\Omega$ can be expressed as a linear combination, with weights $\beta_j$, of k fixed, linearly independent $n \times 1$ vectors $\xi_j^\Omega$
>
> i.e. $\eta_\Omega = \sum_{j=1}^{k} \beta_j \xi_j$ . We say $\eta_\Omega$ belongs to the vector space $V_k$ which is spanned by $\{\xi_j\}$ $j = 1, k$ .
>
> The least squares estimate of $\eta_\Omega$ is $\hat{\eta}_\Omega$ :

$$\hat{\eta}_\Omega = \sum_{j=1}^{k} b_j^\Omega \xi_j^\Omega$$ and $\hat{\eta}_\Omega \in V_k$ and $(y - \hat{\eta}_\Omega) \in V_{n-k}$ which is orthogenal to $V_k$ ([28]).

$(y - \hat{\eta}_\Omega)$ is distributed according to $N(0, \sigma^2 I)$

In this framework, we test the hypothesis H of q linearly independent restrictions. These are typically equality constraints, when H is imposed on $\Omega$, on the price index parameters across models. We call the resulting hypothesis, $\omega$ ([29]).

$$\hat{\eta}_\omega = \sum_{j=1}^{k-q} b_j^\omega \xi^\omega$$ and $\hat{\eta}_\omega \in V_{k-q}$ and $(y - \hat{\eta}_\omega)$ is orthogenal to $V_{k-q}$ which is a subspace, of course, of $V_k$.

Since $\mathcal{F}_{q,n-k}$ is distributed according to the F-distribution with q and $n-k$ degrees of freedom under $\omega$, a test of H with probability of wrong rejection of $\alpha$, is given by: reject H

if $\mathcal{F}_{q,n-k} > F_{\alpha;q,n-k}$ where $\mathcal{F}_{q,n-k} = \dfrac{(\mathcal{S}_\omega - \mathcal{S}_\Omega)/q}{\mathcal{S}_\Omega/n-k}$

and $\mathcal{S}_\omega = \|y - \hat{\eta}_\omega\|^2$, and $\mathcal{S}_\Omega = \|y - \hat{\eta}_\Omega\|^2$.

Given plentiful data and a well fitting maintained hypothesis, this test has high power, i.e. a small probability of making type II error - wrongly accepting H. This causes some difficulty in the choice of the appropriate $\alpha$. Conventional levels such as 5% will not do: they are likely to involve an undesirable trade-off between the probabilities of two types of errors. However, we do not know precisely what the trade-off is. In this classical statistical framework, to calculate the power of the test, it is necessary to know the true values of the parameters ([30]). This, given that different tractor models are allowed different depreciation structures, could involve several hundred parameters, and is clearly not feasible ([31]). For the rest of this paper a significance level = .005 is chosen. Even at this level most null hypotheses we investigate are rejected.

We first consider the hypothesis that large diesel and large gasoline powered tractors aggregate, i.e. have the same price behaviour. From Columns 1, 2, 7 of Table 1, and Chart 1 we can see intuitively that the price behaviour is rather different. This impression is confirmed by the formal test of the hypothesis

$$\log \varpi^{*}_{1,t} = \log \varpi^{*}_{2,t} \qquad t = 1958,1969, \text{ i.e.}$$

equality of the price indices for large diesel and large gasoline tractors, in terms of the model (II.11)

Here $\mathcal{S}_{\Omega} = .2653 + .4470 = .7123$, $\mathcal{S}_{\omega} = .8176$,

$q = 12$, $n = 864$, $k = 329$

$= 5.3$ which considerably exceeds

$F_{(12,433)} = 2.5$ at the .005 level.

We note that except for 1958/9, 1963/5 and 1966/7, large diesel tractors appear to have been appreciating relative to large gasoline tractors. This is consistent with the hypothesis of a demand led switch to diesel power for most of the period ([32]).

Among medium size tractors, however, the story is somewhat different. Examination of Table 1, Columns 3, 4, 8, and Chart 2, reveals that except for 1958/9 and 1966/9, gasoline powered tractors appear to have been appreciating relative to diesel tractors. Again a formal test of the aggregation hypothesis results in its rejection.

Table 2

Efficiency corrected price indices for size/fuel groups

(unequal depreciation structures)

| | 1 Large Gas | 2 Large Diesel | 3 Medium Gas | 4 Medium Diesel | 5 Small Gas | 6 Small Diesel | 7 Large Both Fuels | 8 Medium Both Fuels | 9 Small Both Fuels | 10 All sizes Gas | 11 Small Both Fuels and Medium Gas | 12 WPI code 11.11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1958 | 93.6 | 89.6 | 90.1 | 92.5 | 95.5 | 93.0 | 91.4 | 91.1 | 95.5 | 93.9 | 93.9 | 94.7 |
| 1959 | 103.5 | 95.9 | 96.1 | 100.2 | 99.5 | 99.0 | 99.1 | 97.8 | 99.5 | 98.8 | 98.6 | 98.4 |
| 1960 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 1961 | 97.3 | 104.1 | 98.2 | 97.1 | 99.7 | 101.3 | 100.8 | 97.8 | 99.8 | 99.1 | 99.4 | 102.1 |
| 1962 | 96.8 | 103.8 | 100.2 | 95.9 | 97.4 | 101.9 | 100.4 | 98.1 | 97.9 | 98.2 | 98.6 | 104.1 |
| 1963 | 100.1 | 102.4 | 102.3 | 94.8 | 100.2 | 106.6 | 101.3 | 99.3 | 101.0 | 100.9 | 101.4 | 105.6 |
| 1964 | 103.5 | 104.2 | 103.4 | 96.0 | 100.9 | 107.3 | 103.8 | 100.4 | 101.7 | 102.0 | 102.2 | 106.9 |
| 1965 | 101.7 | 104.1 | 103.2 | 94.5 | 97.2 | 104.0 | 103.0 | 99.6 | 98.2 | 99.9 | 99.8 | 112.0 |
| 1966 | 103.6 | 104.0 | 104.3 | 93.7 | 101.2 | 103.0 | 103.8 | 99.9 | 100.4 | 102.5 | 101.7 | 113.0 |
| 1967 | 107.0 | 108.2 | 104.9 | 96.1 | 103.1 | 105.2 | 107.6 | 101.3 | 102.4 | 104.1 | 103.2 | 116.5 |
| 1968 | 108.4 | 112.1 | 105.6 | 98.8 | 104.0 | 106.4 | 110.4 | 103.0 | 103.4 | 105.1 | 104.1 | 121.3 |
| 1969 | 110.7 | 117.5 | 109.0 | 102.9 | 109.0 | 111.0 | 114.6 | 106.9 | 108.2 | 108.9 | 108.4 | 131.3 |
| SSR | .2653 | .4470 | 2.2744 | 1.1510 | 6.4204 | .6123 | .8176 | 3.5817 | 7.2052 | 9.507 | 9.8495 | |
| nob | 364 | 500 | 1042 | 816 | 1776 | 536 | 864 | 1858 | 2312 | 3185 | 3357 | |
| novar | 132 | 196 | 341 | 287 | 415 | 184 | 317 | 613 | 684 | 915 | 970 | |

Here $\mathcal{S}_{\Omega} = 2.2744 + 1.1510 = 3.4257$, $\mathcal{S}_{\omega} = 3.5817$

$q = 15$ ([33]), $n = 1858$, $k = 628$

$\mathcal{F} = 3.7$, which considerably exceeds $F_{15,1230} = 2.3$

at the .005 level.

The results for small tractors suggest that, except for a few years in the middle of the period, their price behaviour was fairly similar.

Here $\mathcal{S}_{\Omega} = 6.4204 + .6123 = 7.0327$, $\mathcal{S}_{\omega} = 7.2052$

$q = 15$ ([33]), $n = 2312$, $k = 699$

$\mathcal{F} = 2.6$, which exceeds, but by not such a

large margin as for the earlier tests,

$F_{15,1613} = 2.2$ at the .005 level.

However, it must be pointed out that these hypothesis tests are valid if a constant variance can be assumed over each pair of groups for which the aggregation test is performed. This can be tested, since

$$\frac{s_1^2}{s_2^2} \text{ is distributed as } \mathcal{F}_{n_1-k_1,\, n_2-k_2} \text{ if } E(s_1^2) = E(s_2^2),$$

where $s_i^2$ is the sum of squared residuals for group i

divided by the appropriate degrees of freedom $(n_i - k_i)$. While equality of variance is accepted for large tractors and medium tractors (only just for the latter), it is easily rejected for small tractors. There is substantially more unexplained variance in the price behaviour of small gasoline than of small diesel tractors. If a priori information on the relative variances were available, say a ratio of 2 : 1, then the appropriate procedure would be to divide the prices of gasoline tractors by $2^{\frac{1}{2}}$ and carry out the appropriate hypothesis test of aggregation in the transformed (now homoscedastic) model. However, it is not, strictly speaking, rigorous to use the sample value $\frac{s_1^2}{s_2^2}$ to do this ([34]). See (28, 30).

Thus, strictly speaking, none of the aggregation hypotheses can be accepted, though aggregation across small gasoline and small diesel tractors seems to be more plausible than the rest, given the maintained hypotheses ([35]). The index number problem cannot therefore be avoided.

The choice of this six-fold classification as maintained hypothesis has the advantage that production data by size groupings based on horse-power measured at the power take-off is available. There is also data on the relative numbers produced of diesel and gasoline powered tractors. Thus there is some information on the weights that could be used to construct a price index for farm tractors as a whole. If it can be assumed that the prices of used tractors reflect closely transaction prices (as opposed to list prices) for new tractors, current production weights can be used to construct a price index for new tractors. For the stock of used tractors (aged up to 10 years) survival data ([36]) can be combined with historical production data to calculate the appropriate weights ([37]).

The aggregation problem is considered in more detail in a further paper. The starting point there is a framework of maximum generality, which allows model effect/time effect interactions. Within this framework, a hypothesis which allows different price behaviour for each group in a brand/size/fuel classification, is tested. An alternative hypothesis in which each brand has its own price behaviour is also tested. Since this is a not altogether implausible (though less convenient) alternative, brand price indices again allowing different depreciation structures for different models, are presented in Table 3 and Charts 4 and 5. The overall fit of this hypothesis is seen to be rather better, judging by the overall estimated variance (or standard error) ([39]).

TABLE 3 : Efficiency corrected price indices for brands

| | A - C | Case | Deere | Ford | I - H | M - F |
|---|---|---|---|---|---|---|
| 1958 | 97.6 | 96.8 | 87.9 | 87.1 | 87.7 | 97.6 |
| 1959 | 103.0 | 99.5 | 93.1 | 90.8 | 95.0 | 103.1 |
| 1960 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 1961 | 100.3 | 101.7 | 97.4 | 99.7 | 100.0 | 96.3 |
| 1962 | 90.6 | 103.3 | 99.5 | 103.4 | 99.0 | 95.5 |
| 1963 | 92.7 | 103.0 | 103.0 | 113.4 | 102.4 | 96.7 |
| 1964 | 93.4 | 102.7 | 104.4 | 114.8 | 105.5 | 96.7 |
| 1965 | 91.7 | 102.3 | 105.0 | 111.5 | 100.5 | 95.8 |
| 1966 | 95.5 | 102.8 | 105.0 | 110.4 | 103.9 | 96.0 |
| 1967 | 97.5 | 107.5 | 106.5 | 110.3 | 106.3 | 97.4 |
| 1968 | 98.3 | 112.1 | 108.4 | 110.0 | 107.0 | 99.4 |
| 1969 | 102.6 | 120.6 | 113.4 | 112.0 | 109.3 | 103.3 |
| S.S.R. | 2.8144 | 1.9522 | .5809 | .3706 | 1.9360 | 1.3917 |
| nob | 748 | 925 | 722 | 565 | 1227 | 854 |
| novar | 201 | 310 | 267 | 214 | 438 | 262 |

However, if the poorest fitting group is removed for each classification, the estimated variance (or standard errors) for the remaining groups for each classification is very similar ([38]). Informally then, there seems little to choose between the two alternative 'maintained hypotheses'.

## V. Testing the 'Cagan-Hall hypothesis'

In this section, the hypothesis of identical depreciation structures between models over given segments of the market is investigated. Its link with the names Cagan and Hall needs some justification. Cagan ( 2 ), assumed equal depreciation across models for a given 'line' (e.g. low priced Chevrolet six cylinder) ([40]). In addition, he adopted the constraint of constant geometric depreciation [41]. We do not concern ourselves with the latter hypothesis for the moment. Hall also assumed equal depreciation structures across the models (vintages) for a given brand (Ford or Chevrolet) of pick-up trucks [42]. The closest one could come to testing the analogous hypothesis for farm tractors in the present framework, would be to test for equality of depreciation structures across models for a given brand. This can be done in the framework of the size/fuel disaggregation but giving each brand its own depreciation structure, where the maintained hypothesis allows each model its own depreciation structure. These results are not complete and all that can be said at present is that the hypothesis is accepted for several groups.

A test of a somewhat more stringent hypothesis than the Cagan/Hall hypothesis as strictly understood, is to test for equal depreciation structures across all models for each size/fuel group. Regression results for price indices and depreciation rates estimated in this framework are reported in table 4. For ease of comparison, price indices estimated with equal and with unequal depreciation rates across models, are presented in charts 1-3. As can be readily observed, the patterns of price movements under the two methods are similar.

Table 5 presents formal tests of the hypothesis in the context of each of the size/fuel groups.

Table 4: Efficiency corrected price indices for size/fuel groups: equal depreciation structures across models in each group

| | large gas | large diesel | medium gas | medium diesel | small gas | small diesel |
|---|---|---|---|---|---|---|
| 1958 | 99.3 | 87.8 | 91.1 | 92.9 | 99.9 | 94.0 |
| 1959 | 107.0 | 94.3 | 97.2 | 100.4 | 100.1 | 102.0 |
| 1960 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 1961 | 98.4 | 105.1 | 98.2 | 98.1 | 98.7 | 99.8 |
| 1962 | 98.7 | 107.5 | 100.1 | 96.4 | 96.1 | 99.3 |
| 1963 | 102.2 | 106.3 | 101.5 | 96.4 | 98.6 | 103.6 |
| 1964 | 104.7 | 107.6 | 102.3 | 97.2 | 98.8 | 105.0 |
| 1965 | 103.2 | 107.1 | 100.2 | 95.5 | 94.7 | 102.4 |
| 1966 | 104.9 | 105.7 | 101.3 | 94.0 | 97.6 | 101.0 |
| 1967 | 108.2 | 110.0 | 101.4 | 96.3 | 98.6 | 103.7 |
| 1968 | 110.1 | 113.4 | 101.8 | 98.8 | 99.0 | 105.1 |
| 1969 | 113.1 | 117.9 | 104.8 | 102.6 | 105.2 | 110.6 |
| | Depreciation indices | | | | | |
| age=1 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2 | .923 | .921 | .918 | .918 | .916 | .917 |
| 3 | .855 | .852 | .847 | .844 | .839 | .842 |
| 4 | .785 | .784 | .786 | .778 | .775 | .775 |
| 5 | .719 | .721 | .732 | .718 | .715 | .710 |
| 6 | .659 | .663 | .683 | .666 | .660 | .645 |
| 7 | .604 | .610 | .636 | .617 | .613 | .590 |
| 8 | .556 | .569 | .588 | .568 | .566 | .537 |
| 9 | .509 | .528 | .543 | .517 | .522 | .494 |
| 10 | .462 | .483 | .499 | .474 | .481 | .449 |
| $R^2$ | .997 | .995 | .976 | .987 | .977 | .992 |
| SSR | .4156 | 1.2272 | 4.9100 | 2.3601 | 13.1282 | 1.0487 |
| nob | 367 | 500 | 1045 | 820 | 1780 | 537 |
| novar | 39 | 51 | 62 | 57 | 87 | 43 |
| confidence intervals: | | | | | | |
| for 1960 price index | 103.7 to 96.4 | 105.9 to 94.4 | 104.7 to 95.5 | 102.9 to 97.1 | 105.0 to 95.2 | 103.8 to 96.4 |
| for age=5 depr.index | .722 to .708 | .739 to .704 | .748 to .716 | .732 to .704 | .731 to .700 | .728 to .703 |

Table 5: Testing the equal depreciation hypothesis in the framework of size/fuel disaggregation

| | $\mathcal{F}$ statistic* | $\mathcal{S}_\omega$ | $\mathcal{S}_\Omega$ | q | nob-novar |
|---|---|---|---|---|---|
| Large gas | 1.41 | .4156 | .2653 | 93 | 232 |
| Large diesel | 3.66 | 1.2272 | .4470 | 145 | 304 |
| Medium gas | 2.91 | 4.9100 | 2.2744 | 279 | 701 |
| Medium diesel | 2.42 | 2.3601 | 1.1510 | 230 | 529 |
| Small gas | 4.34 | 13.128 | 6.4204 | 328 | 1361 |
| Small diesel | 1.78 | 1.0487 | .6123 | 141 | 352 |

* critical values are all around 1.55 to 1.6 given these degrees of freedom.

At the .005 level, formal tests reject the hypothesis for 5 out of 6 size/fuel groups, although one is only marginally rejected. It is not surprising perhaps that this group (small diesel) and large gas for which equal depreciation across models is accepted should both have relatively few models.

The equal depreciation hypothesis was also investigated in the brand disaggregation. Price and depreciation indices are presented in table 6. The formal tests are summarized in table 7.

Table 6: Efficiency corrected price indices and depreciation indices for brands: equal depreciation across models for each brand

| | A-C | Case | Deere | Ford | I-H | M-F |
|---|---|---|---|---|---|---|
| 1958 | 98.9 | 98.1 | 87.4 | 87.0 | 88.6 | 99.8 |
| 1959 | 102.8 | 100.0 | 92.4 | 88.5 | 96.6 | 103.7 |
| 1960 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 1961 | 98.9 | 102.1 | 99.0 | 100.4 | 100.7 | 96.0 |
| 1962 | 89.3 | 103.7 | 102.2 | 104.1 | 101.0 | 96.4 |
| 1963 | 89.8 | 103.8 | 108.3 | 112.1 | 105.7 | 96.6 |
| 1964 | 89.8 | 103.8 | 110.5 | 113.9 | 107.9 | 96.7 |
| 1965 | 88.2 | 100.9 | 111.4 | 110.9 | 102.4 | 96.0 |
| 1966 | 91.6 | 100.8 | 111.3 | 109.7 | 104.7 | 96.1 |
| 1967 | 92.6 | 105.1 | 112.9 | 109.4 | 107.1 | 97.8 |
| 1968 | 93.5 | 109.7 | 114.1 | 108.2 | 108.2 | 99.8 |
| 1969 | 97.8 | 118.2 | 118.3 | 111.0 | 114.5 | 103.9 |
| age=1 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2 | .923 | .914 | .918 | .917 | .926 | .919 |
| 3 | .866 | .833 | .842 | .845 | .851 | .848 |
| 4 | .803 | .765 | .774 | .779 | .786 | .785 |
| 5 | .743 | .709 | .713 | .719 | .727 | .721 |
| 6 | .688 | .656 | .662 | .665 | .669 | .663 |
| 7 | .632 | .602 | .615 | .620 | .621 | .605 |
| 8 | .578 | .546 | .568 | .575 | .570 | .552 |
| 9 | .530 | .491 | .526 | .534 | .523 | .501 |
| 10 | .489 | .443 | .483 | .504 | .476 | .454 |
| $R^2$ | .991 | .985 | .992 | .991 | .988 | .989 |
| SSR | 4.5972 | 3.6270 | 1.4670 | .7459 | 4.4566 | 3.7809 |
| nob | 751 | 925 | 722 | 565 | 1231 | 855 |
| novar | 48 | 58 | 58 | 52 | 77 | 55 |
| confidence intervals: | | | | | | |
| for 1960 price index | 105.2 to 95.0 | 103.6 to 96.5 | 105.4 to 94.9 | 104.6 to 95.6 | 102.5 to 97.5 | 105.6 to 94.7 |
| for age=5 depr.index | .765 to .722 | .724 to .695 | .726 to .699 | .732 to .707 | .740 to .714 | .739 to .703 |

Table 7: Testing the equal depreciation hypothesis in the framework of brand disaggregation

| | $\mathcal{F}$ statistic | $S_\omega$ | $S_\Omega$ | $q$ | nob-novar |
|---|---|---|---|---|---|
| AC | 2.26 | 4.5972 | 2.8144 | 153 | 547 |
| Case | 2.09 | 3.6270 | 1.9522 | 252 | 615 |
| Deere | 3.39 | 1.4670 | .5809 | 206 | 458 |
| Ford | 2.19 | .7459 | .3706 | 162 | 351 |
| IH | 2.85 | 4.4566 | 1.9360 | 361 | 789 |
| MF | 9.50 | 3,7810 | 1.3917 | 107 | 592 |

At the .005 level, the hypothesis is rejected for every brand. In a sense, this can be regarded as reassuring. Earlier, the brand disaggregation was found not to be noticeably superior to the fuel/size disaggregation.

This latest piece of information shows that brand effects do not simultaneously dominate price and depreciation behaviour. This suggests that features that might be associated with market imperfections such as strong brand advertising and brand loyalty more generally [43], are probably not very powerful.

## VI. Testing the 'Hedonic Hypothesis'

In terms of the theory set out in Section II, we assume that the production structure can be expressed by

$$F(q\,x;\ v_1,\ v_2,\ \ldots,v_m.\ g\ (c_1,\ c_2\ \ldots\ c_r)) = 0$$

where $c_1$, $c_2$ ... $c_r$ are the levels of the performance characteristics and $v_m$ = services from the mth capital input.

This replaces the assumption

$$F(q\,x;\ v_1,\ \ldots,v_m.h(b)) = 0 .$$

If we supposed that the function $g(c_1,\ c_2\ \ldots\ c_r)$ fulfilled the condition $\frac{\partial g}{\partial c_i} \Big/ \frac{\partial g}{\partial c_j}$ = constant, the implication of constant relative shadow prices of the characteristics would follow given that technological change did not affect $g(\ )$. The reasons for this are as follows: Using the arguments in Muellbauer (26), the cost function which, given the above technology, relates the economy's total production cost to the fixed output vector q x and input prices $w_1$ ... $w_m$, has the form

$$C = C(q\,x;\ w_1\ \ldots\ w_{m-1},\ \frac{w_m}{g\ (c_1,c_2\ \ldots c_r)}) .$$

$-\frac{\partial C}{\partial c_i}$ can be interpreted as the shadow price of the ith characteristic .

But $\dfrac{-\partial C}{\partial c_i} \Big/ \dfrac{-\partial C}{\partial c_j} = \dfrac{\partial g}{\partial c_i} \Big/ \dfrac{\partial g}{\partial c_j}$ = constant under the above

assumption.

Whether or not g( ) is in this simple form, the arguments of Section II leading up to the empirically testable model (II.12)

$$\log u_{i,t,\tau} = \log \omega^*_t + \log D_{i,\tau} + \log b_i + \epsilon_{i,t,\tau} ,$$

go through as before. Now however, we hypothesize that $b_i = g(c_{i1}, c_{i2}, \ldots c_{ir})$. It is interesting to note that the semi-logarithmic form of the hedonic hypothesis which has been used in empirical work with prices of new goods, here is

$$\log b_i = \sum_{j=1}^{r} \alpha_j c_{ij}$$

ie.

$$b_i = \prod_{j=1}^{r} (e^{\alpha_j c_{ij}})$$

With this form, the relative shadow prices are given by $\left(\dfrac{\alpha_i}{\alpha_j}\right)$ for $i,j=1 \ldots r$. If this form of $g(c_1, c_2 \ldots c_r)$ is valid and technological change did not directly affect the form and parameters of g( ), the semi-log form would imply constancy of the relative prices of the characteristics even though the relative prevalent levels of the characteristics were changing.

The results presented below are for a form which says that $b_i$ is a constant elasticity function of maximum lb. pull, fuel economy measured in h.p. hours per gallon, PTO h.p., and the number of gears and a semilog (ie. $\log b_i =$

$$\sum_{j=1}^{4} \alpha_j \log c_{ij} + \sum_{j=5}^{r} \alpha_j c_{ij})$$

form in dummy variables measuring whether the fuel is diesel or gasolene, the presence of a basic hydraulic system, an auxiliary hydraulic system, an independent power take off, power steering, power adjusted rear tread, and a three point hitch. In addition brand dummies are included where applicable. The interpretation of the first four parameters is of elasticities eg. $\alpha_3$ measures the percentage increase in quality (or price, holding time and age constant) implied by a 1% increase in PTO h.p.. Constancy of the elasticities over time implies that variations in the relative levels of the characteristics result in inverse variations in the relative shadow prices i.e.

$$\frac{\text{shadow price}_i}{\text{shadow price}_j} \propto \frac{c_j}{c_i}$$

which has considerable intuitive appeal. The exponential of each of the remaining parameters measures the proportionate difference in quality attributable to the presence of the characteristic.

This hedonic hypothesis is a linear constraint on a maintained hypothesis in which each model is allowed its own quality index: every vintage in a production run of a given model is constrained to have the same quality index under both hypotheses. In addition of course, the hedonic form introduces constraints across models. Price indices, depreciation indices and other parameter estimates are presented in tables 8a), 8b), 9b) under the two alternative disaggregations. Tests are presented in Tables 10 and 11.

It must be admitted that these tests are prejudiced against the hedonic technique as presently used in research on prices of new goods. Firstly, although the hypothesis of equal depreciation across models in a given group was not accepted for the majority of groups in Section V, it was simply not feasible to use the regression method necessary to estimate the parameters of the characteristics, to estimate the large number of parameters implied by unequal depreciation structures. Secondly the relative values of the parameters (although as explained, not the shadow prices of the first four characteristics) in the hedonic constraint are assumed constant over time. This is equivalent to the pooled regression with time dummies approach explained in Section III. It is argued in the concluding section that Griliches' strictures on sensitivity to the vagaries of sample selection of the time dummy method, probably do not apply here. Nevertheless, some attempt must be made to meet his criticism on non-constancy of the relative shadow prices of the characteristics. Two points can be made.

We have

$$b_i = \prod_{j=1}^{4} c_{ij}^{\alpha_j} \prod_{k=5}^{13} e^{\alpha_k c_{ik}}$$

The shadow price of horsepower, abstracting from overall price change, is

$$\left(\frac{\alpha_3}{c_{i3}}\right)\left(\prod_{j=1}^{4} c_{ij}^{\alpha_j}\right)\left(\prod_{k=5}^{13} e^{\alpha_k c_{ik}}\right)$$

Table 8(a): Hedonic price indices and depreciation indices for fuel/size groups

| | large gas | large diesel | medium gas | medium diesel | small both fuels |
|---|---|---|---|---|---|
| 1958 | 98.9 | 88.1 | 90.5 | 93.2 | 92.9 |
| 1959 | 106.8 | 94.5 | 96.5 | 100.3 | 98.8 |
| 1960 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 1961 | 98.6 | 104.5 | 99.3 | 98.9 | 101.8 |
| 1962 | 99.0 | 106.1 | 102.3 | 98.0 | 101.5 |
| 1963 | 102.6 | 103.5 | 104.5 | 98.8 | 108.7 |
| 1964 | 105.3 | 104.5 | 106.8 | 100.0 | 112.4 |
| 1965 | 104.1 | 104.1 | 104.6 | 98.4 | 110.6 |
| 1966 | 106.4 | 104.8 | 106.4 | 97.8 | 114.8 |
| 1967 | 109.9 | 108.7 | 107.5 | 100.9 | 117.7 |
| 1968 | 112.0 | 112.7 | 109.0 | 104.6 | 118.3 |
| 1969 | 115.5 | 117.9 | 112.9 | 109.2 | 127.5 |
| Depreciation indices | | | | | |
| age=1 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2 | .923 | .923 | .910 | .915 | .908 |
| 3 | .854 | .853 | .836 | .840 | .826 |
| 4 | .782 | .782 | .769 | .771 | .749 |
| 5 | .715 | .716 | .709 | .708 | .677 |
| 6 | .652 | .652 | .658 | .654 | .611 |
| 7 | .597 | .599 | .609 | .603 | .554 |
| 8 | .548 | .564 | .558 | .552 | .498 |
| 9 | .501 | .528 | .511 | .499 | .447 |
| 10 | .454 | .488 | .466 | .454 | .401 |
| $R^2$ | .990 | .944 | .889 | .935 | .919 |
| SSR | .4951 | 3.5889 | 10.0422 | 4.4329 | 53.356 |
| nob | 367 | 500 | 1045 | 820 | 2317 |
| novar | 34 | 34 | 38 | 38 | 40 |
| confidence intervals: | | | | | |
| for 1960 price index | 119.6 to 83.6 | 108.2 to 92.4 | 106.6 to 93.8 | 105.9 to 95.0 | 106.1 to 94.2 |
| for age=5 depr. index | .729 to .701 | .740 to .692 | .730 to .689 | .725 to .691 | .698 to .657 |

Table 8(b): Estimated parameters of characteristics for fuel/size groups

| | large gas | large diesel | medium gas | medium diesel | small both fuels |
|---|---|---|---|---|---|
| pull | .10 (.05) | - .03 (.05) | .62 (.05) | .35 (.04) | .35 (.03) |
| fuel cons. | .43 (.09) | - .30 (.10) | .01 (.07) | .30 (.05) | .13 (.06) |
| PTO h.p. | 1.02 (.06) | .65 (.07) | .19 (.07) | .67 (.04) | .33 (.03) |
| gears | .07 (.04) | - .23 (.09) | - .14 (.02) | .02 (.02) | .10 (.01) |
| AC | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Case | .73 | 1.04 | .92 | 1.01* | 1.21 |
| Deere | 1.28 | .91 | 1.13 | 1.06 | 1.40 |
| Ford | .72 | .67 | 1.00* | .91 | 1.48 |
| I-H | 1.19 | 1.04* | 1.04* | 1.02* | 1.33 |
| MF | .76 | .59 | .84 | .86 | 1.17 |
| hydr.1 | - | - | - | - | .89 |
| hydr.2 | 1.06 | 1.02* | .97 | .99* | 1.05 |
| PTO | .99* | 1.27 | 1.24 | 1.03 | 1.06 |
| p.steering | - | - | 1.08 | .99* | .96 |
| p.adj.tread | 1.09 | 1.40 | .98* | 1.01 | 1.16 |
| 3pt.hitch | 1.04 | 1.10 | 1.03 | 1.04 | .94 |
| diesel | - | - | - | - | 1.07 |

The parameters in the first four rows are elasticities. They are followed by standard errors in brackets. The remaining parameters measure the percentage differential in price if the relevant characteristic is present.

* means not significantly different from 1.

\- means that for reasons of collinearity the relevant dummy was not included in the regression.

## Table 9(a): Hedonic price indices and depreciation indices for brands

| | A-C | Case | Deere | Ford | I-H | M-F |
|---|---|---|---|---|---|---|
| 1958 | 96.4 | 98.4 | 87.4 | 87.1 | 83.7 | 97.8 |
| 1959 | 101.5 | 100.0 | 92.2 | 90.8 | 94.8 | 103.0 |
| 1960 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 1961 | 102.6 | 101.7 | 99.3 | 100.2 | 102.1 | 97.1 |
| 1962 | 95.1 | 102.9 | 102.6 | 103.9 | 104.6 | 98.2 |
| 1963 | 99.0 | 102.8 | 109.1 | 112.8 | 105.4 | 99.0 |
| 1964 | 101.7 | 103.6 | 111.3 | 114.9 | 113.4 | 100.0 |
| 1965 | 102.3 | 99.8 | 112.4 | 112.3 | 108.0 | 100.1 |
| 1966 | 109.1 | 100.7 | 111.9 | 111.5 | 110.8 | 101.7 |
| 1967 | 113.6 | 105.2 | 113.3 | 111.4 | 113.5 | 104.7 |
| 1968 | 117.7 | 110.3 | 114.4 | 111.1 | 114.4 | 108.2 |
| 1969 | 126.0 | 118.4 | 119.3 | 117.3 | 119.1 | 113.9 |
| age=1 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2 | .918 | .912 | .919 | .912 | .924 | .913 |
| 3 | .844 | .830 | .844 | .834 | .849 | .834 |
| 4 | .766 | .758 | .778 | .764 | .778 | .763 |
| 5 | .693 | .702 | .718 | .705 | .716 | .692 |
| 6 | .626 | .650 | .664 | .651 | .654 | .631 |
| 7 | .562 | .597 | .615 | .606 | .601 | .570 |
| 8 | .502 | .543 | .566 | .562 | .545 | .518 |
| 9 | .448 | .490 | .522 | .522 | .492 | .466 |
| 10 | .401 | .444 | .479 | .494 | .441 | .418 |
| $R^2$ | .980 | .966 | .987 | .9769 | .951 | .979 |
| SSR | 10.069 | 8.1804 | 2.5645 | 1.9199 | 18.387 | 7.0982 |
| nob | 751 | 925 | 722 | 565 | 1231 | 855 |
| novar | 35 | 33 | 34 | 33 | 35 | 34 |
| confidence intervals: | | | | | | |
| for 1960 price index | 116.2 to 86.0 | 105.5 to 94.7 | 104.3 to 95.9 | 108.2 to 92.4 | 10[illegible].7 to 92.8 | 107.2 to 93.3 |
| for age=5 depr. index | .722 to .666 | .723 to .682 | .733 to .703 | .722 to .688 | .739 to .693 | .713 to .672 |

Table 9(b): Estimated parameters of characteristics for brands

| | A-C | Case | Deere | Ford | I-H | M-F |
|---|---|---|---|---|---|---|
| pull | - .02 (.1) | - .07 (.05) | .41 (.03) | .07 (.02) | - .12 (.05) | - .01 (.05) |
| fuel cons. | - .6 (.1) | .38 (.05) | .19 (.04) | .34 (.06) | - .53 (.09) | - .63 (.08) |
| PTO h.p. | .87 (.1) | .86 (.05) | .59 (.03) | .59 (.03) | .93 (.04) | .79 (.05) |
| gears | .23 (.05) | .08 (.02) | .12 (.02) | .06 (.02) | - .11 (.03) | .11 (.02) |
| hydr.1 | 1.42 | - | - | - | .86 | - |
| hydr.2 | 1.17 | .93 | 1.02 | 1.02 | 1.08 | .93 |
| PTO | .99* | 1.20 | 1.04 | 1.11 | 1.01* | 1.11 |
| p.steering | .85 | 1.19 | .99* | 1.17 | 1.09 | 1.18 |
| p.adj.tread | .92 | - | 1.02 | - | 1.08 | .96 |
| 3pt. hitch | .86 | 1.01* | .92 | 1.04 | .98* | 1.24 |
| diesel | 1.31 | 1.05 | 1.03 | 1.02* | 1.26 | 1.41 |

* means not significantly different from 1.

Given constancy of $\alpha_3$ and $o<\alpha_3 < 1$, the trend toward higher horsepower over the period, will, other things being equal, result in a secular decline in the shadow price of horsepower. The results presented in tables 8b) and 9b) show that, irrespective of whether the brand disaggregation or the fuel/size disaggregation is chosen, the hypothesis that $o < \alpha_3 < 1$ is accepted in every case. Thus implied in the constancy of $\alpha_3$ is a declining (relative) shadow price of horsepower. This is consistent with Fettig's results ( 7 ), Table 12. The coefficient of h.p. in his semi-log single year regressions declines from .0108 (.0005) in 1954 to .0088 (.0005) in 1958 to .0068 (.0003) in 1962, where the standard errors follow in parentheses. On the other hand, the form in which the diesel dummy variable enters above, does not imply Fettig's result of a secular decline in the shadow price of diesel. The diesel variable is excluded of course where diesel and gasoline tractors are treated separately and this objection is of no account there.

Secondly, as was pointed out in Section III above, Fettig's results from pooled regression are quite similar to those obtained by the methods using adjacent year regression or single year regression with chain linked specifications weights. This suggests that the above form of the hedonic constraint, may after all, not be such an unreasonable restriction.

We turn now to the formal hypothesis tests of the hedonic constraint. These are summarized in tables 10 and 11 for the two alternative disaggregations. It is clear that this form of the hypothesis is much more strongly rejected than any of the hypotheses tested in the earlier part of this paper. It also seems to make

Table 10: Testing the hedonic constraint in the framework of size/fuel disaggregation

| | $\tilde{f}$ statistic | $f_{\omega}$ | $f_{\Omega}$ | $q$ | nob-novar |
|---|---|---|---|---|---|
| Large gas | 12.5 | .4951 | .4156 | 5 | 328 |
| Large diesel | 50.8 | 3.5889 | 1.2272 | 17 | 449 |
| Medium gas | 42.8 | 10.042 | 4.9100 | 24 | 983 |
| Medium diesel | 35.3 | 4.4329 | 2.3601 | 19 | 763 |
| Small | 85.9 | 53.356 | 14.375 | 70 | 2217 |

Table 11 : Testing the hedonic constraint in the framework of brand disaggregation

| | $\tilde{f}$ statistic | $f_{\omega}$ | $f_{\Omega}$ | $q$ | nob-novar |
|---|---|---|---|---|---|
| A-C | 64.4 | 10.069 | 4.597 | 13 | 703 |
| Case | 43.5 | 8.180 | 3.627 | 25 | 867 |
| Deere | 20.7 | 2.5645 | 1.4670 | 24 | 664 |
| Ford | 42.5 | 1.9199 | .7459 | 19 | 513 |
| IH | 85.9 | 18.387 | 4.457 | 42 | 1154 |
| MF | 33.4 | 7.098 | 3.781 | 21 | 800 |

little difference in which disaggregation of the sample we test.

It is interesting to examine the differences between the price and depreciation indices presented in tables 8a) and 9a) and the earlier results of tables 4 and 6 with equal depreciation across models, and of tables 2 and 3 with each model allowed its own depreciation structure. In almost every case, the hedonic constraint results in higher estimated inflation and faster depreciation. This seems to be the case particularly for Allis-Chalmers and Massey-Ferguson among the brands and small tractors in the size groups. The general shape of the graphs is similar: it is just that the hedonic constraint seems to imply a very different overall inflation trend for these categories and a somewhat different trend for medium sized tractors and Ford and International Harvester among the brand groups. The estimated price and depreciation indices using the different methods, turn out to be very similar for large tractors and Case and Deere in the brand groups.

The discrepancy for Allis-Chalmers seems to be partly due to large, high priced tractors that enter the sample in 1966 and 1967. If these are inadequately explained by the hedonic constraint but are free to take their own quality indices under the methods presented earlier, this could result in a higher implied rate of inflation for the hedonic method. Something similar appears to be also occurring with Massey Ferguson. One observes, for example, two large tractors of similar specifications both observed in 1969. one is 1962 vintage, one is 1968 vintage. Give the depreciation structures and the parameter estimates for the characteristics, the latter vintage has a price which is 'too high' i.e. can be explained in the model only by inflation. On the other hand, this inflation does not appear to be occurring among the 1965 or pre-1965 vintages or indeed for the 'new' models once introduced. Thus, the poor fit of the hedonic constraint.

The behaviour seems to be consistent with two alternative hypotheses. One is that the characteristics are only partial measures of quality - which would partly be a problem of the adequacy of the specification information. Thus it may be that the 1968 vintage referred to above has a superior cab - safer and more comfortable and hydraulic equipment which is more sophisticated. These are examples of improvements which our specification information does not pick up. A second explanation is that even in **parts of the used market, buyers are poorly informed and/or** that pricing is semi-administered i.e. that tractor dealers use rules of thumb which relate used prices to new prices regardless of how buyers react. Connected with this one would have to argue that manufacturers use new models to introduce price increases and keep prices relatively constant thereafter.

For some manufacturers however, John Deere, for example, the hedonic hypothesis gives very similar results. Presumably Deere does not use such pricing tactics (perhaps because its market power is so strong that price rises can be successfully carried through at any time without the necessity for disguising them through the introduction of new models). Alternatively, one might argue that the second hand market in Deere tractors is much closer to being competitive with better informed buyers. A conclusive interpretation is hard to come by. Nevertheless some attempt is made at some overall evaluations in Section VII.

## VII. Conclusions

We begin with some discussion of the list of assumptions made explicit in section II above. In items A.1 and A.2 we noted that there were circumstances under which either because of the nature of deterioration and quality change or because of insufficient substituability, the efficiency of an older good may suddenly become zero because of say, a wage increase. This problem, if it exists is evaded to some extent by using data on tractors aged up to ten years only. The results suggest that a ten year old tractor is worth much less than 40 % of a one year old tractor. Factor mobility is clearly adequately satisfied. We have already discussed aspects of the competitiveness of the used tractor market. There are a number of reasons why used market measurements are likely to be superior to measures from the new market. There will have been some depreciation of the impact of the advertising which accompanies the launching of a new model. More information, based on experience, on the reliability of the model will have become available on the farmers' grapevine. In addition the prices are claimed to be sample means of prices actually paid. New list prices vary from prices paid to an unknown degree.

One of the big problems of constructing price indices is to link in the model changes: often models are not observed in the market at the same point of time, which is the major reason for the use of the hedonic method. The used market enables one to observe many more models priced simultaneously (given that the depreciation structures are well defined.)

A final point which could be important is that the stocks in the used market are, to a close approximation, fixed. Depending on the market structure, the suppliers on the new market may be quantity rather than price adjustors so that relative prices may not reflect relative qualities very well. On the used market, prices are forced to reflect more closely the valuations of the buyers. This suggests that the problems which Griliches and others attempt to overcome by weighting their observations by sales, are considerably less prevalent, at least for the larger part of the market.

There are good reasons to suppose that except occasionally with a high degree of disaggregation, variability in the composition of the sample is not a serious problem for this tractor data. Each model, even each vintage, is observed over a number of years: There is a typically, a gradual phasing in and out of each model: the first year that the model enters it is typically represented by 1 price (age = 1), the next year by two prices (age = 1,2) and so on. At the other end, vintages aged over ten years disappear, so that the representation becomes less and less. On the other hand, for a high degree of disaggregation, it is possible that sample variability adversely affects the results.

The price indices presented in tables 2 and 3 were obtained by linking price change indices calculated in a simple but general framework. They are averages of relative prices of adjacent years, holding model and age fixed (see appendix A). The method assumes that the quality of a model is fixed only in adjacent year comparisons and, of course, allows each model its own depreciation structure . As far as the price index is concerned, Griliches points about allowing the relative shadow prices of the underlying quality determinants to vary over time is to a large extent met: in other words, there is a sort of chain linking built into the method. Once the resulting values of the price indices are obtained, than a quality index (fixed over time) for each model can be calculated. However the validity of this and the technique which imposes equal depreciation structures across models, rest heavily on the competitiveness of the market: central is the idea that if two tractors (which may be of different models and/or different in age) compete on the same market at the same point in time, their relative prices reflect relative efficiencies. If this is not largely correct, the method does not give meaningful results. One might argue then, that poor though the fit of the hedonic constraint may be relatively speaking, by introducing a constraint on quality across models, it shows up the hidden inflation (if such exists) which lack of competitiveness allows manufacturers to introduce together with their own models.

My interpretation of the results presented above is the following: tables 3 and 6 which show results for brand disaggregation without the hedonic constraint, suggest that the price behaviour of tractors produced by Allis-Chalmers and Massey-Ferguson is peculiar. Since these are relatively small producers, my interpretation is that the market is too thin for the reported prices to be very realistic for at least part of the model range of these brands. This suggests that for these brands there may be something in the second of the two alternative hypotheses suggested at the end of section VI.

Some support for this comes from the fact that table 6 and even more strongly table 3 show that the standard errors of the regressions, (i.e. $\left[SSR/(nob - novar)\right]^{\frac{1}{2}}$) are highest for these two brands. Since the hypothesis of equal depreciation across models was rejected, I regard the results of table 3 as more reliable than those of table 6. Since over the period 1958 - 1969, the overall efficiency corrected price change of the other manufacturers was roughly similar, between 22 % and 28 % inflation (from table 3), this suggests that the downward bias in inflation for A - C and M - F is probably introducing a downward bias into the rates implied by the fuel/size disaggregation. However, it is not clear whether this affects the relative price changes between the size/fuel groups.

Some light may be thrown on all this by looking at the hedonic results of tables 8(a) and 9(a). Now the price behaviour of A - C and M - F looks much less peculiar, which makes sense in view of what has been said above. In the framework of the size/fuel disaggregation, this additional information suggests the price indices reported for small tractors in tables 2 and 4 are probably downward biased. This suggests that the small models produced by A - C and M - F probably have the most atypical price behaviour. It is worth pointing out, by the way, that the parameters of the brand dummies presented in table 8(b) cannot be taken at face value because some of the characteristics are almost colinear with some of the brand dummies. In addition it is worth noting that the conclusions of Hall and Dhrymes that the parameters of the characteristics are different for different segments of the market, are supported.

This throws some additional weight behind the comments made in section III on disaggregating over time when it is at the price of mispecification cross-sectionally. Over 1958 to 1969, I conclude from table 2 in the light of the other information and reasoning, that large diesel tractors increased in price more than large gasoline tractors: about 30 % inflation in large diesel, and about 20 % in large gasoline tractors. Among medium tractors however, there was about 20 % inflation for gasoline tractors and a little over 10 % for diesel tractors. The hedonic method gives a slightly lower rate for large gas tractors : this I regard as a consequence of the assumption of equal depreciation across models introduced for computational reasons. The large gas results of table 4 compared to table 2 also show this effect. Otherwise for large and medium tractors the hedonic method implies slightly more inflation. This I view as a consequence of it not picking up all the quality improvements that took place. The results for small tractors are the least reliable and here the divergence between the hedonic and the more general method is most dramatic. Table 2 suggests about 15 % and 19 % for gas and diesel respectively. This is probably too low, but the figure of about 37 % for the hedonic method for small tractors as a whole is almost certainly too high : it seems hardly consistent with the switch to larger tractors over the period.

For the period 1958 to 1962 it is possible to compare my results with those of Fettig. All the alternative methods used in this paper suggest a figure which while less than the WPI component's 10 % inflation is not significantly less than 5 %. Fettig, on the other hand, suggests zero inflation. This is disturbing. It could mean that the new and used markets move rather independently. However, a more plausible interpretation is that there was more discounting from list prices at the beginning of that period. The BLS tries to incorporate such information in the figures it collects for some, at least, of its indices. Although Fettig followed a suggestion by Griliches (14) in examining the relative behaviour of new and used prices to get some idea of whether this sort of thing might be happening, the data he cites from Griliches (14), applies only to the period before 1958.

In relation to the Wholesale Price Index, Farm and Garden Tractor Component, if second hand tractors are reasonably competitive with new tractors, there can be no doubt that the official index takes insufficient account of quality improvement. The inflation rate of 38 % reported there is too large by at least 10 percentage points and probably by more. There has been some controversy in the context of hedonic price measurement recently about whether there is a consistent upward bias in the official price indices because of inadequate allowance for quality change. The results presented here throw interesting light on this. They suggest that there is such an upward bias in the WPI, Farm and Garden Tractor Component. However, it may well be that because of superior accuracy of the BLS's price collection system in regard to discounting and variable trade-ins (and possibly because it has access to more accurate weighting data) there are particular cases where the hedonic technique used on list prices of new goods gives results further from realistic figures than the official price indices.

It is clear that a fair amount of work remains to be done, including:

- a more systematic examination of the differences in quality indices implied by the hedonic constraint and those given by the more general (Cagan-Hall) maintained hypothesis.
- examination of more detailed engineering information for selected model comparisons.

This should throw some light on the fundamental issues raised at the end of the previous section. If for example, on the basis of more complete engineering information, it became clear that there is no significant physical difference between the two Allis-Chalmers models to which reference has been made, this would support the contention implied above, that the Cagan-Hall method should not be used uncritically for the whole tractor market.

Further, an examination of the hedonic hypothesis in a context which favours it would be necessary to meet the objection that the tests carried out were prejudicial. This could be done by single or adjacent year regression given a reasonable set of equality constraints on depreciation structures across models. This, of course, would no longer be in the framework which constrains all tractors of a given model to have the same depreciation structure over time.

The hypothesis that there is some secular shift in depreciation structures can be examined in our original framework by relating a model's depreciation with the middle year of the production run for that model, over models.

Work is also required on the hedonic constraint in this respect: crude tests for secular changes in the relative shadow prices can be carried out.

Finally, as already suggested, aggregation needs to be investigated further. In particular, the fundamental issues of independence of the depreciation indices of time given model and age, and of the independence of quality indices of time given age can be examined (although not simultaneously) in a model which permits such interactions. Formal tests of the hypothesis of no interactions are certainly feasible, though probably at the cost of not using some of the data because the relevant parameters simply cannot be identified.

Footnotes

{ 1 } That paper, (26) was a natural development from two papers (24), (25) which recast the two fundamental papers by Fisher and Shell (10), (11), into what has been called the 'duality approach' in consumer and producer theory.

{ 2 } There are two sensible reference levels of utility between which to choose : that which can be attained with a given income under base period prices and under current period prices respectively, see (10), (24).

{ 3 } If x is taken to be the base period vector of output proportions, there are nevertheless two sensible values of $\underline{q}$ to take as reference levels. They are the maximum respective levels at which x can be produced given input prices $\hat{w}$ and w respectively given a fixed money total cost. The former is adopted in (26).

{ 4 } As proved in (26), p.5.

{ 5 } More generally, an efficiency change since we will want to include ageing.

{ 6 } This, Fisher-Shell (10) call the 'simple repackaging case' in their discussion of quality change (for consumers) as it affects the cost-of-living index. It is worth noting that what they would call the 'variable repacking case' i.e.

$$F(\underline{q}x;\ v_1 \ldots v_{m-1},\ g(b,\ v_m)) = 0$$

reduces formally to the simple case if there is constant returns.

{ 7 } It is assumed that h(b) is a monotonic increasing function of b.

{ 8 } See F. M. Fisher ( 9 ) for further discussion of this point.

{ 9 } Except where we want to consider several different models produced in a given year : then we shall want a quality index for each.

{ 10 } The other assumptions are clearly met. The assumption of independence is very plausibly the weakest. It denies the existence of interaction terms. Below, in appendix A, a model is discussed in which the interactions that appear most likely to occur, are formalized.

{ 11 } The absence of corner solutions in the problem of maximizing w.r.t. v the real output level q with a given money cost at fixed input prices.

{ 12 } So was twice differentiability of the cost function and the production structure.

{ 13 } Efficient allocation has to be assumed to get even remotely plausible conditions for aggregation. See F. M. Fisher ( 9 ) and May ( 23).

{ 14 } Another reason for time/model interactions may be that aggregation is not working.

{ 15 } See previous footnote and section IV below.

{ 16 } See Jorgenson and Griliches ( 21 ), Johansen and Sørsveen (20). and Tice (32).

{ 17 } See Cagan ( 2 ), p. 226.

{ 18 } Earlier, no account had been taken of price concessions by dealers i.e. discounts or large trade-in allowances. During 1954-1956, this information began to be collected and incorporated.

{ 19 } It is worth noting that the WPI component has been adjusted in most of this period by cost data provided by manufacturers.

{ 20 } Identifying restrictions are introduced by constraining some adjacent years' quality indices to be equal. Specification information was used to arbitrate these constraints.

{ 21 } Though not necessarily across brands or other groupings.

{ 22 } Some reasons why this might happen were given under A.4, Section II.

{ 23 } Dhrymes interprets this ascasting doubt on the interpretation of the shadow prices of characteristics as implicit consumer valuations. He instead suggests that they suggest 'cost plus markup relations' for manufacturers.

{ 24 } From cross-sections alone, parameters for separate brands could not be identified.

{ 25 } Apparently Griliches originally suggested a related idea.

{ 26 } Some of these had to guessed from comparable models where the direct data were not available.

{ 27 } The issue is clarified at the beginning of section VI below.

{ 28 } That is, $V'_{n-k}$ is spanned by n-k linearly independent. (n x 1) vectors which are orthogenal to $V_k$ j = 1, k.

{ 29 } We can think of $\Omega$ and $\omega$ denoting the parameter spaces of the respective probability distributions under the two hypotheses, i.e. $\Omega = \{\beta_1 \ldots \beta_k, \sigma^2\}$ and $\omega = \{\beta_1 \ldots \beta_{k-q}, \sigma^2\}$.

{ 30 } This enables one to calculate the non-centrality parameter $\delta$ which together with q and n-k, completely determines the distribution (non-central F) of $\mathcal{F}$ under $\Omega$.

{ 31 } This suggests that a Bayesian approach might have been more appropriate. This would have enabled one to compare the 'plausibility' of the two hypotheses given the probability distribution of the observations and a prior distribution on the parameters. Ideally, a full decision theoretic approach would be required. For this we would, in addition, require a utility function specifying how the costs and benefits to the decision maker vary with the loss of information in aggregation and the gains in easier data handling. For some principles of such an approach see W. D. Fisher ( 12 ).

{ 32 } Production figures reported by the Industry Division, Bureau of the Census show such a trend but do not, of course, by themselves reveal whether it was demand led.

{ 33 } Although price indices are presented only for 1958-1969, the data permitted estimation for 1955-1969. However, the sample coverage is poor for 1955-58, and this shows itself in poor estimates.

{ 34 } See Scheffé ( 28 ), Stein ( 30).

{ 35 } The same difficulty applies to testing for aggregation across all gasoline tractors and medium gasoline tractors/small tractors both fuels. For this reason, formal tests of these hypotheses are not presented.

{ 36 } See Parsons ( 27) and Fox ( 13 ).

{ 37 } Unfortunately, from England I have been unable to obtain the relevant data for a large enough period. In addition, the relative production data on diesel/gasoline farm tractors does not distinguish between size classes. The assumption that the same diesel/gasoline proportion applies in each size class does not seem very plausible.

{ 38 } Paradoxically, the high variance for small gasoline tractors suggests that further <u>dis</u>aggregation might be in order i.e. starting with a more general maintained hypothesis.

{ 39 } However, one observes that small gasoline tractors might be disaggregated by brands, at least into Allis-Chalmers, Case and the rest. Similarly in the brand classification, Allis-Chalmers and Case might be disaggregated into small and medium-large groups. Examination of price change indices for individual models for Allis-Chalmers' small gasoline tractors reveals some very untypical behaviour - untypical both of the brand as a whole and of small tractors as a whole.

{ 40 } Defining a 'manufacturer's 'line' sometimes involves some arbitrary decisions. Cagan admits, ( 2 ) p. 226-227, that in cases of doubt, lines were specified according to list price. However, deciding the manner of disaggregation on the basis of the observed dependent variables is not, in general, proper procedure. The random element in the observations from one population is likely to cause the observations for which there are larger disturbances to be systematically grouped with the adjacent population.
This causes a tendency for the estimated parameters from adjacent populations to be biased towards each other.

{ 41 } Such a constraint was rejected by Hall for pick-up trucks.

{ 42 } He also tested and accepted the hypothesis that the two brands behaved identically in this respect.

{ 43 } Which might be created, say, by one manufacturer systematically offering higher trade-in allowances for older tractors of his make.

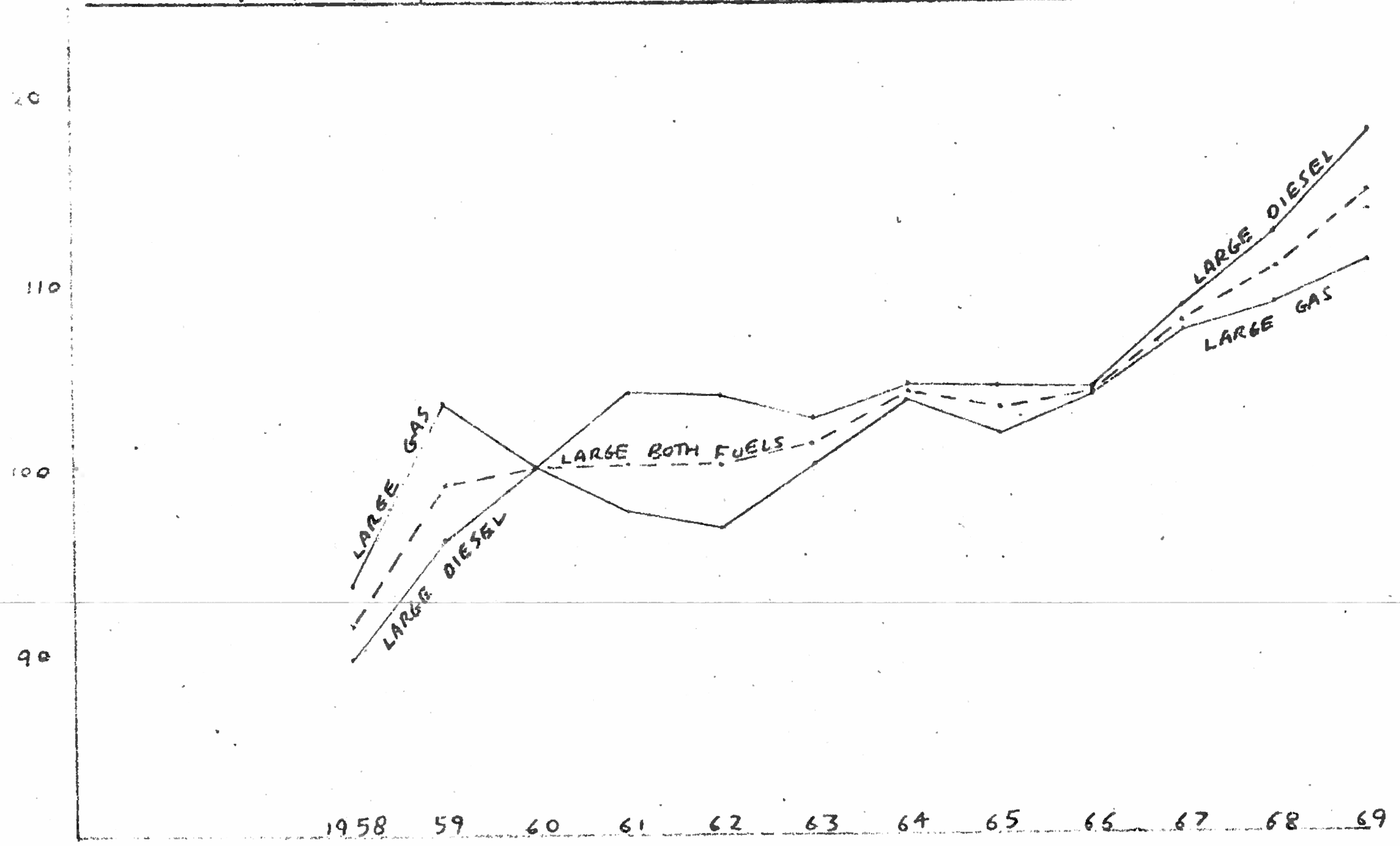
(44) Since efficiency differences between capital services from the models in a particular group are assumed of the simple repackaging type, we can aggregate over services from different goods. Hence for a given aggregate, there is a common efficiency corrected rental price $w_t^*$.

This way of presenting the last step is slightly to be preferred to Hall's. He introduces an efficiency corrected (stock) price of a capital good defined

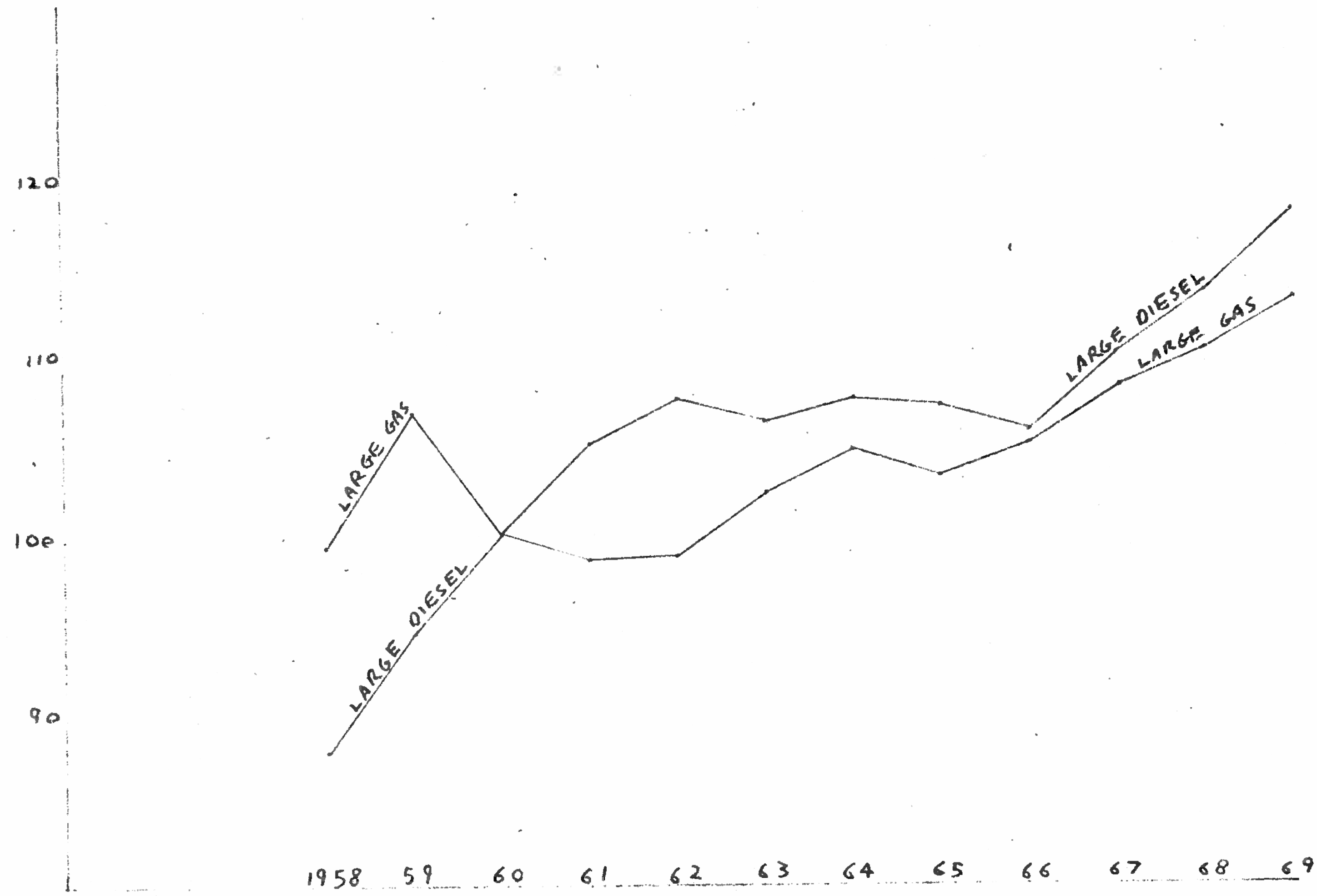
as $\bar{P}_t = w_t^* \sum_{s=0}^{N-2} \left(\frac{1}{1+r}\right)^s \phi_i$ in my notation.

This price $\bar{P}_t$ is supposed to be a general price index for a group of capital goods. But, strictly speaking, if this aggregation is to be possible we would need to assume one identical depreciation structure, and one expected life across models.

CHART 1: EFFICIENCY CORRECTED PRICE INDICES FOR LARGE TRACTORS

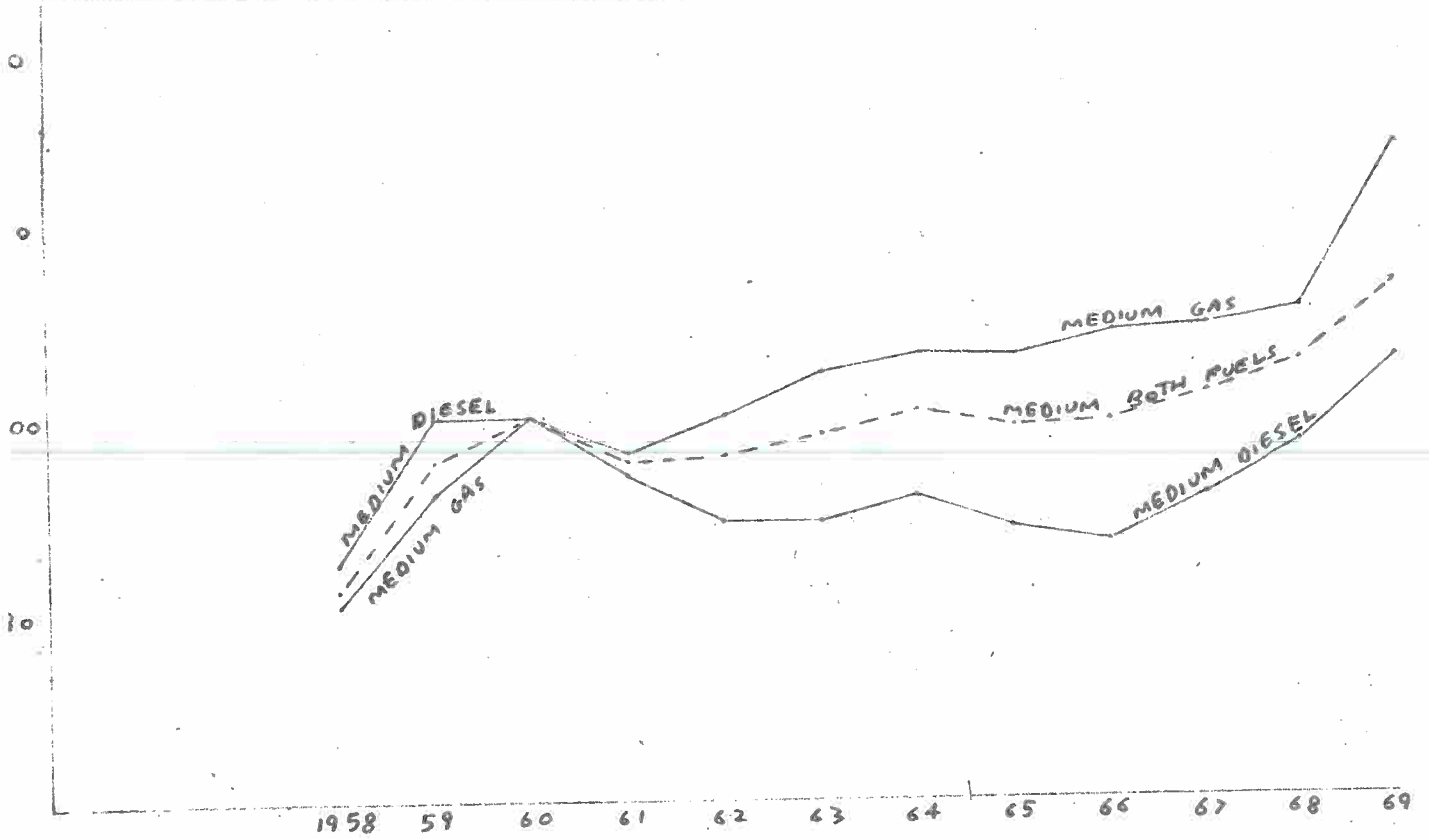



UNEQUAL DEPRECIATION STRUCTURES

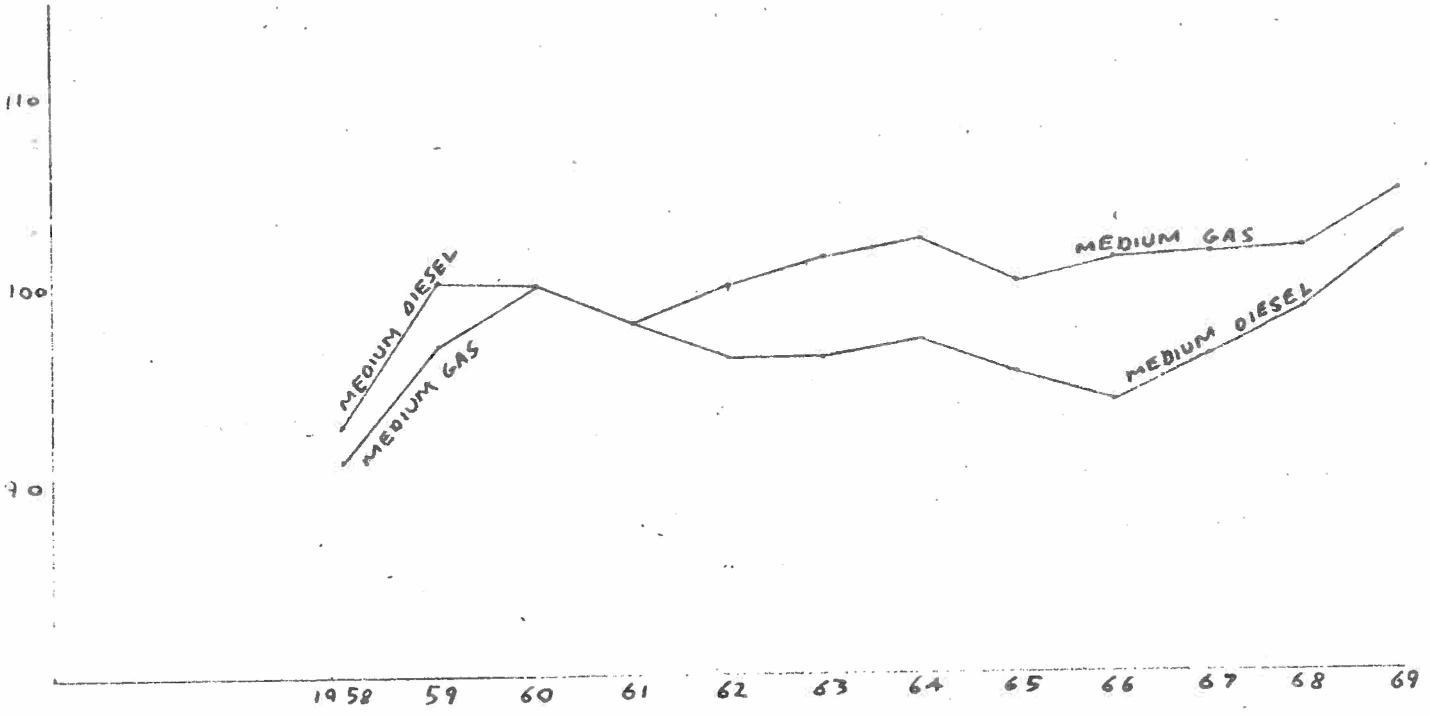



EQUAL DEPRECIATION STRUCTURES

CHART 2 : EFFICIENCY CORRECTED PRICE INDICES FOR MEDIUM TRACTORS

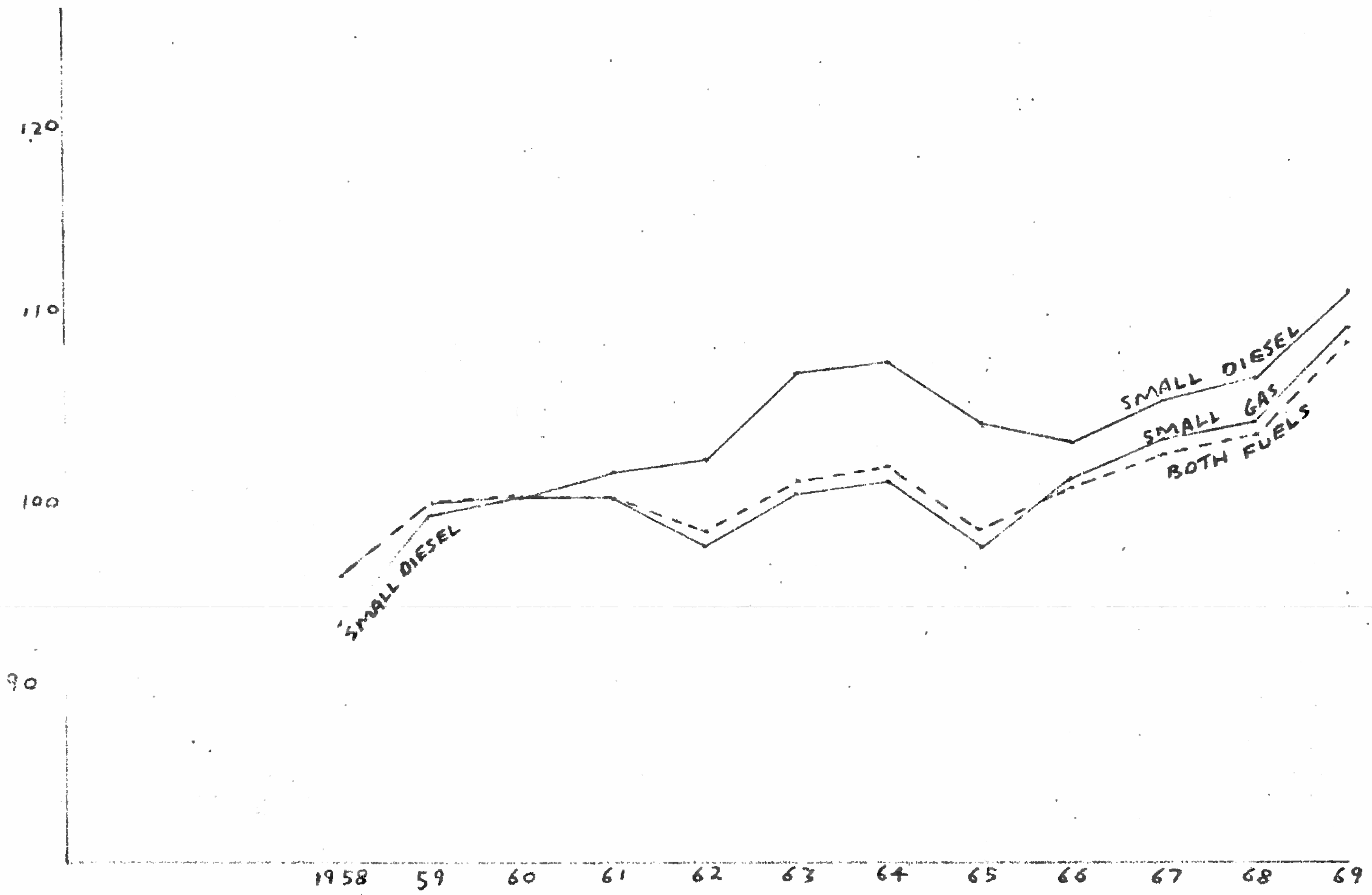



UNEQUAL DEPRECIATION STRUCTURES

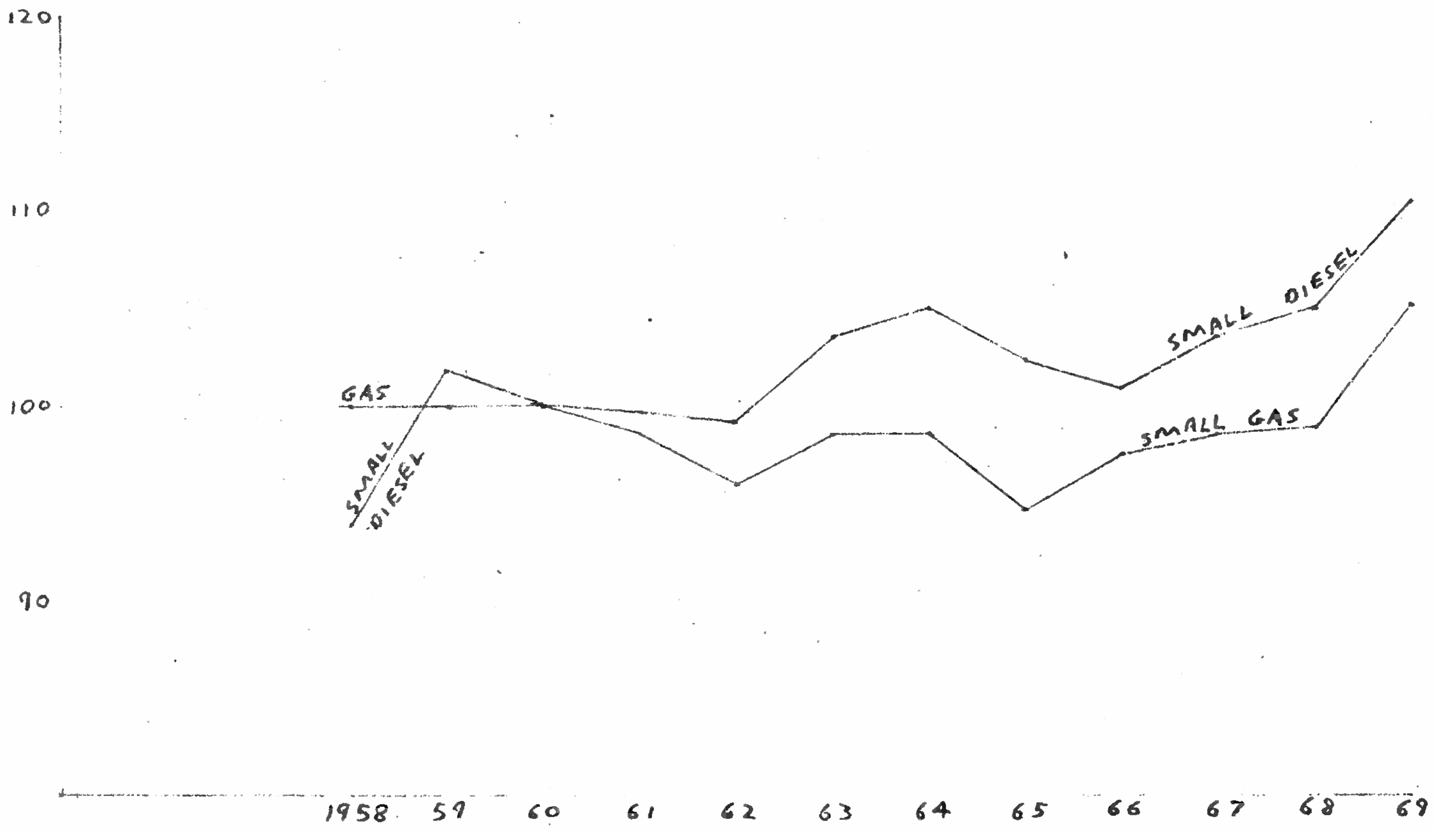



EQUAL DEPRECIATION STRUCTURES

## CHART 3 : EFFICIENCY CORRECTED PRICE INDICES FOR SMALL TRACTORS



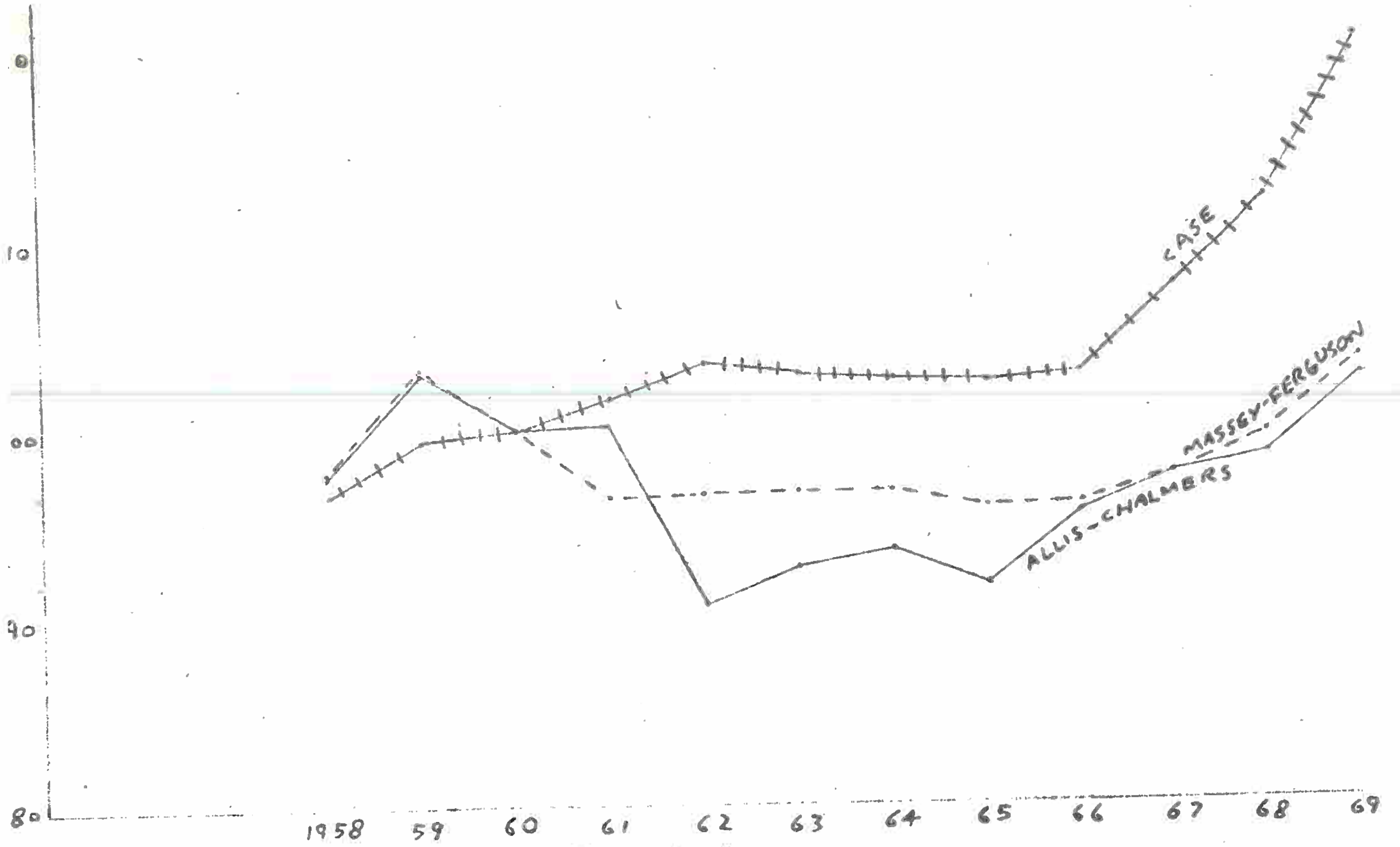

UNEQUAL DEPRECIATION STRUCTURES



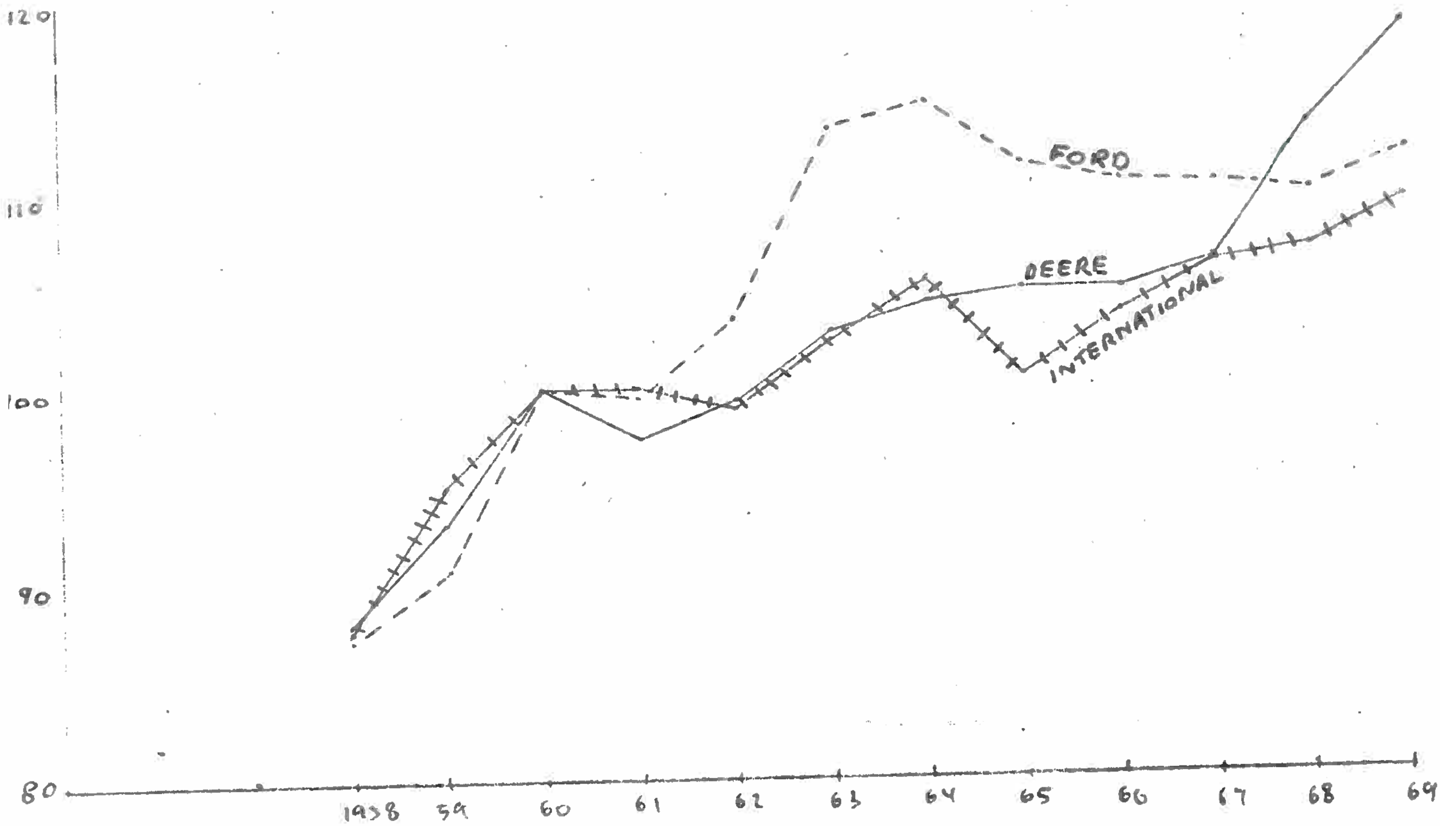

EQUAL DEPRECIATION STRUCTURES

CHART 4: EFFICIENCY CORRECTED PRICE INDICES FOR BRANDS

UNEQUAL DEPRECIATION RATES BETWEEN MODELS



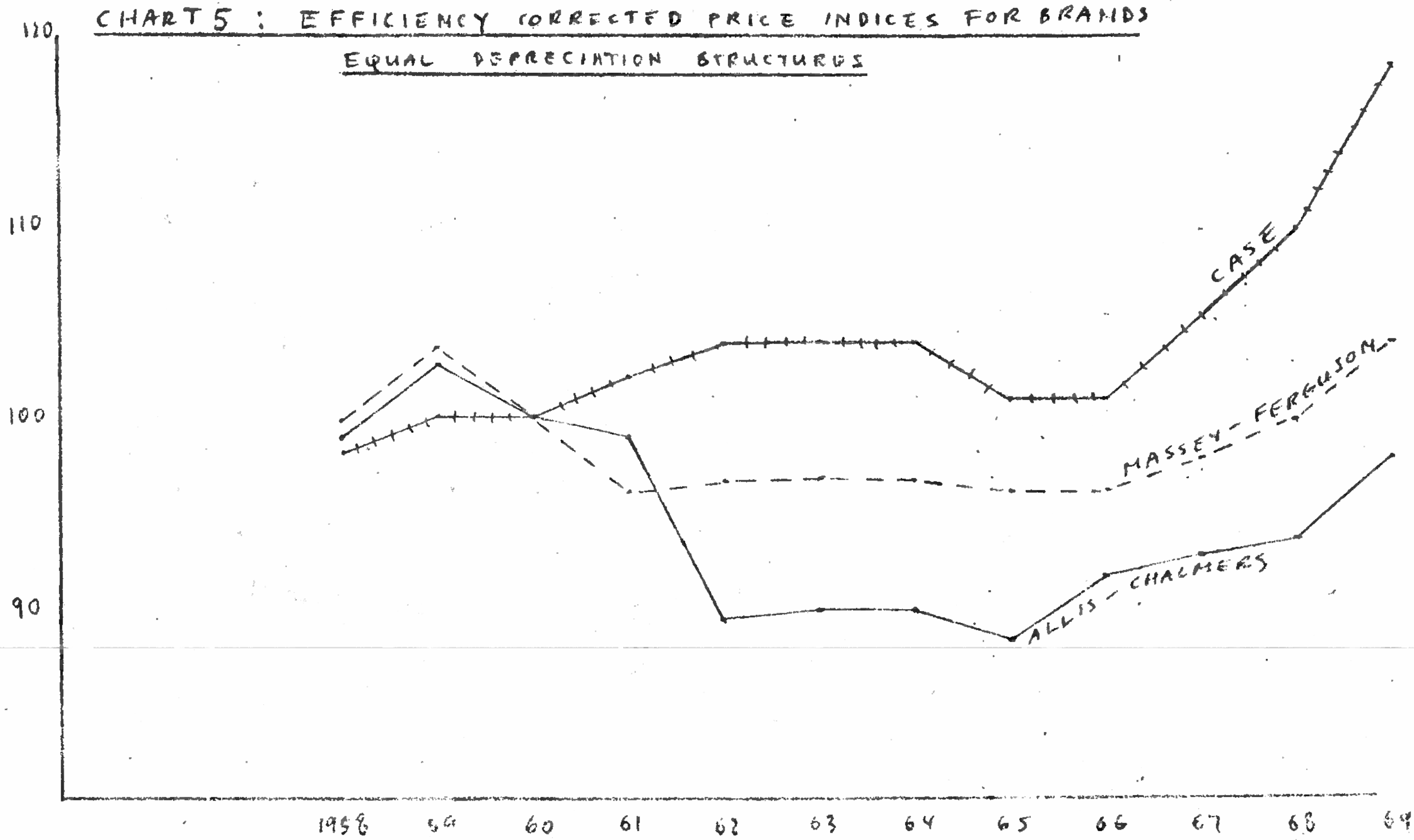

SMALLER MANUFACTURERS




LARGER MANUFACTURERS

CHART 5 : EFFICIENCY CORRECTED PRICE INDICES FOR BRANDS

EQUAL DEPRECIATION STRUCTURES

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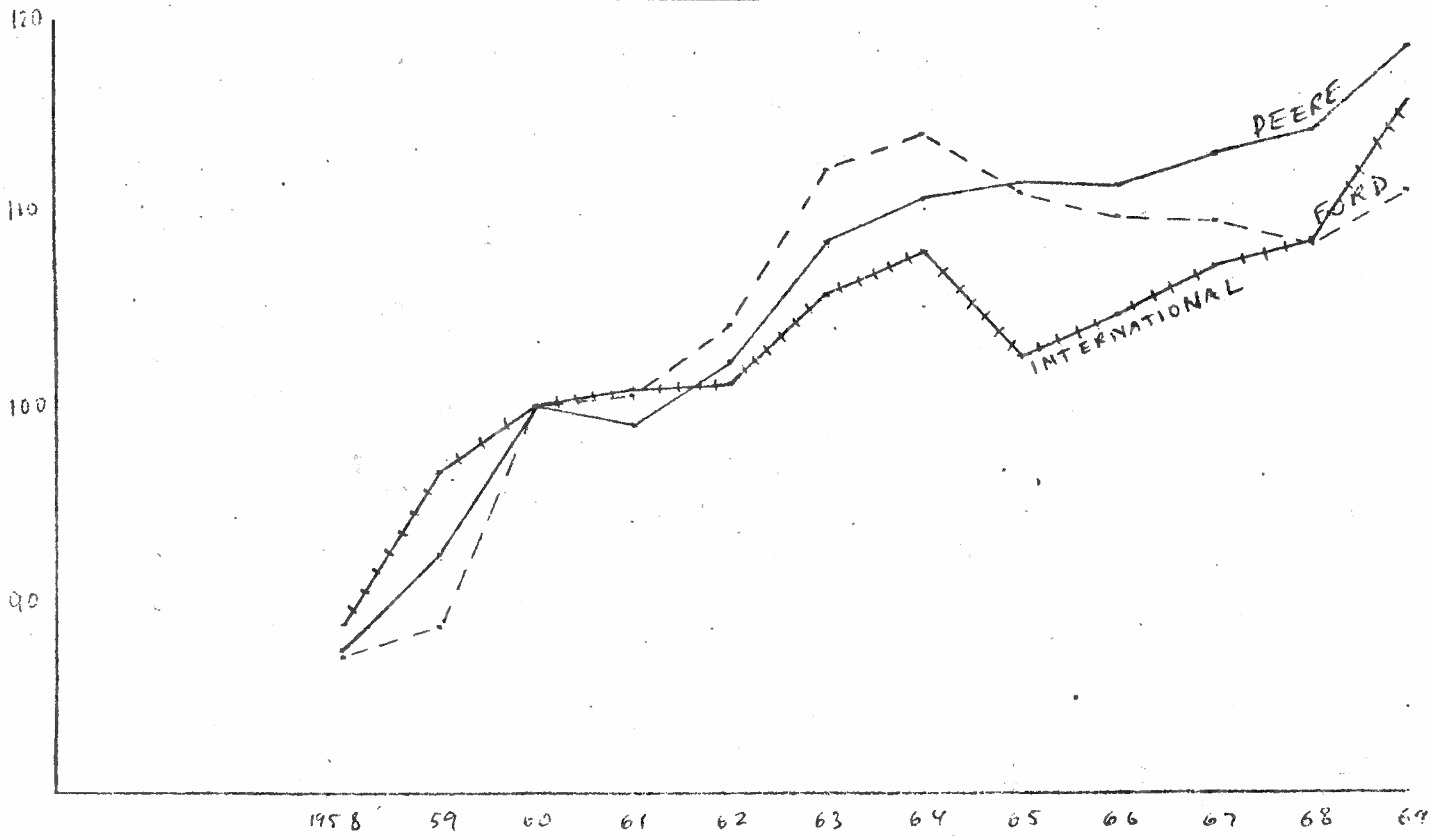
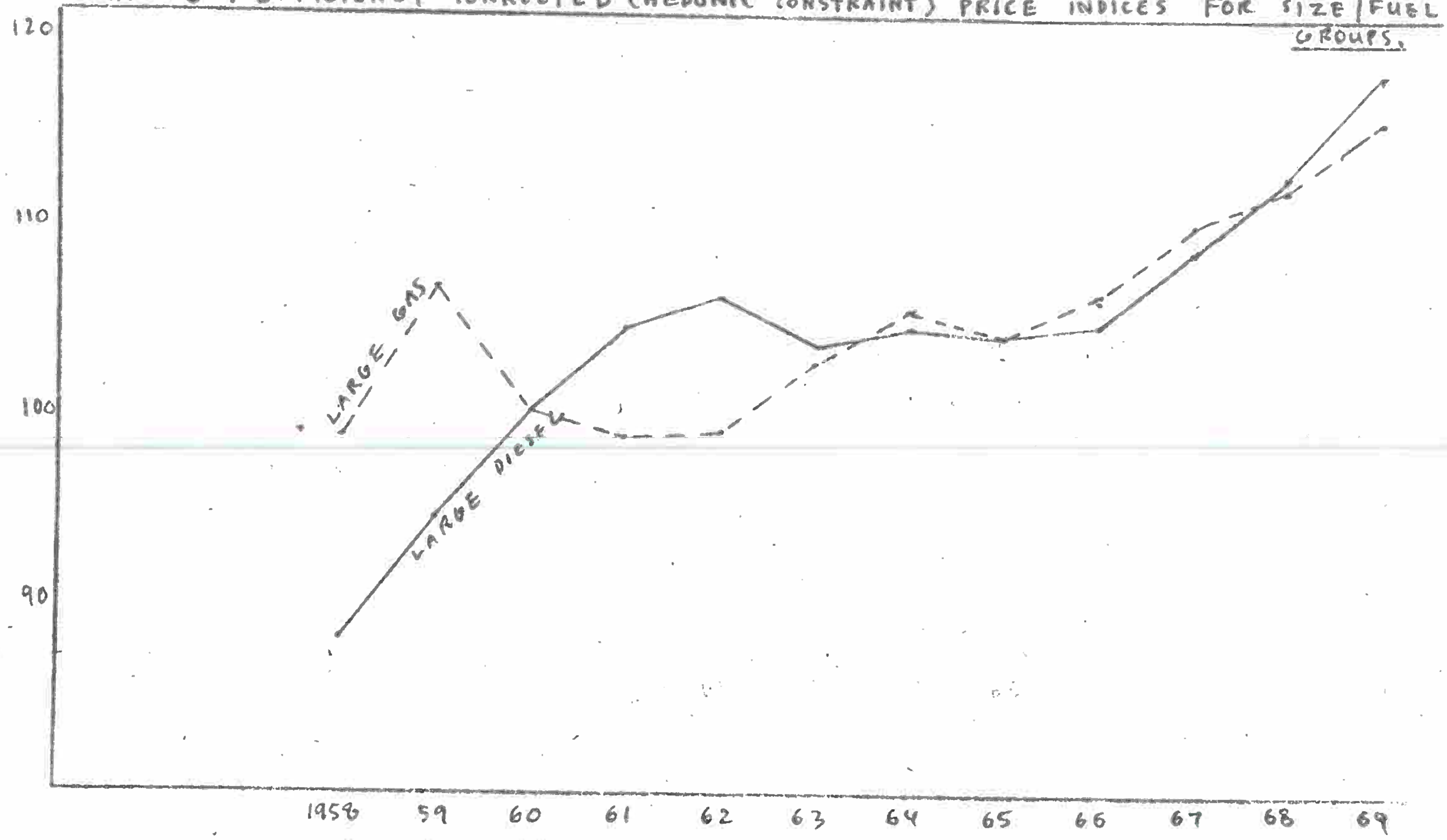
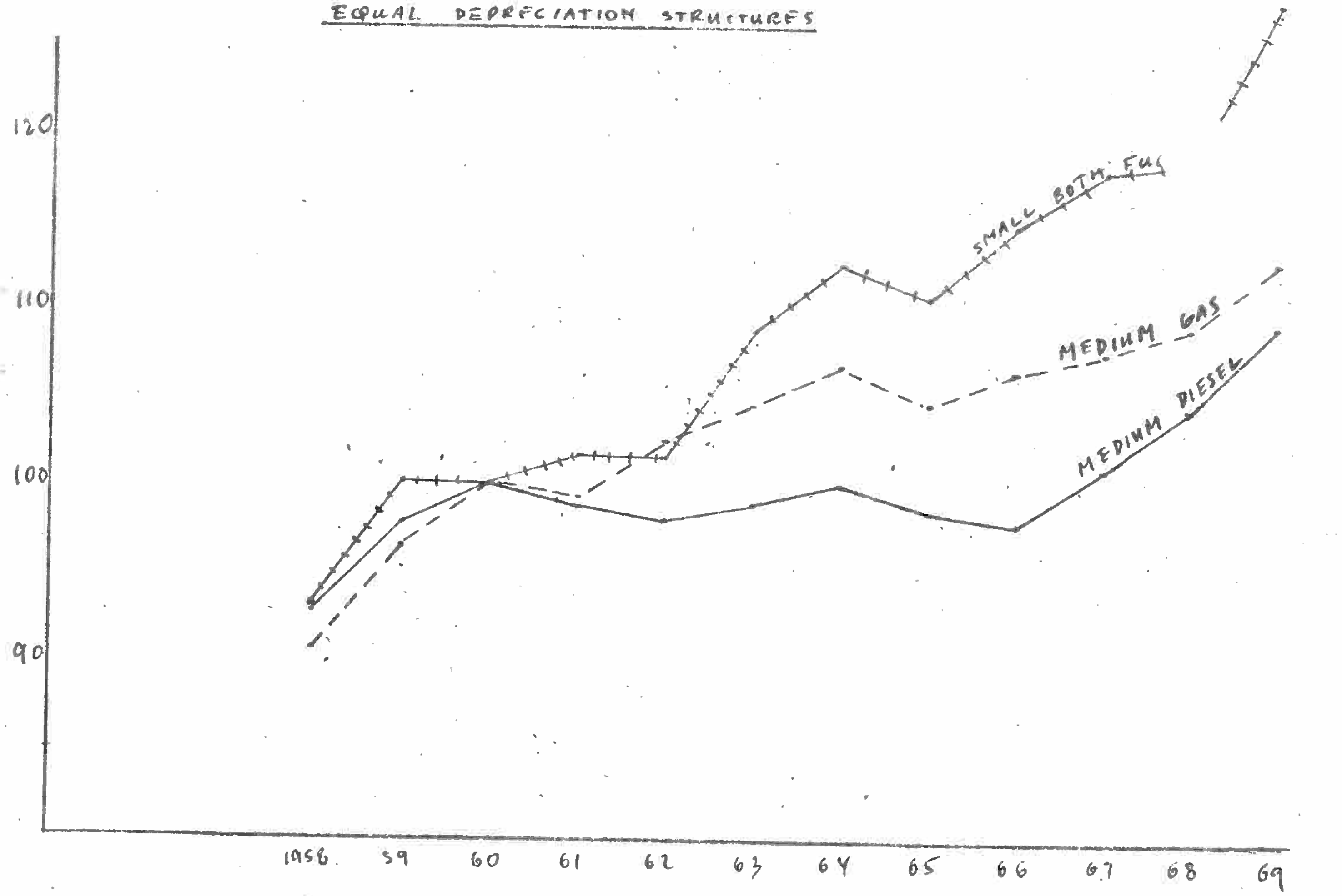



LARGER MANUFACTURERS

CHART 6 : EFFICIENCY CORRECTED (HEDONIC CONSTRAINT) PRICE INDICES FOR SIZE/FUEL GROUPS.



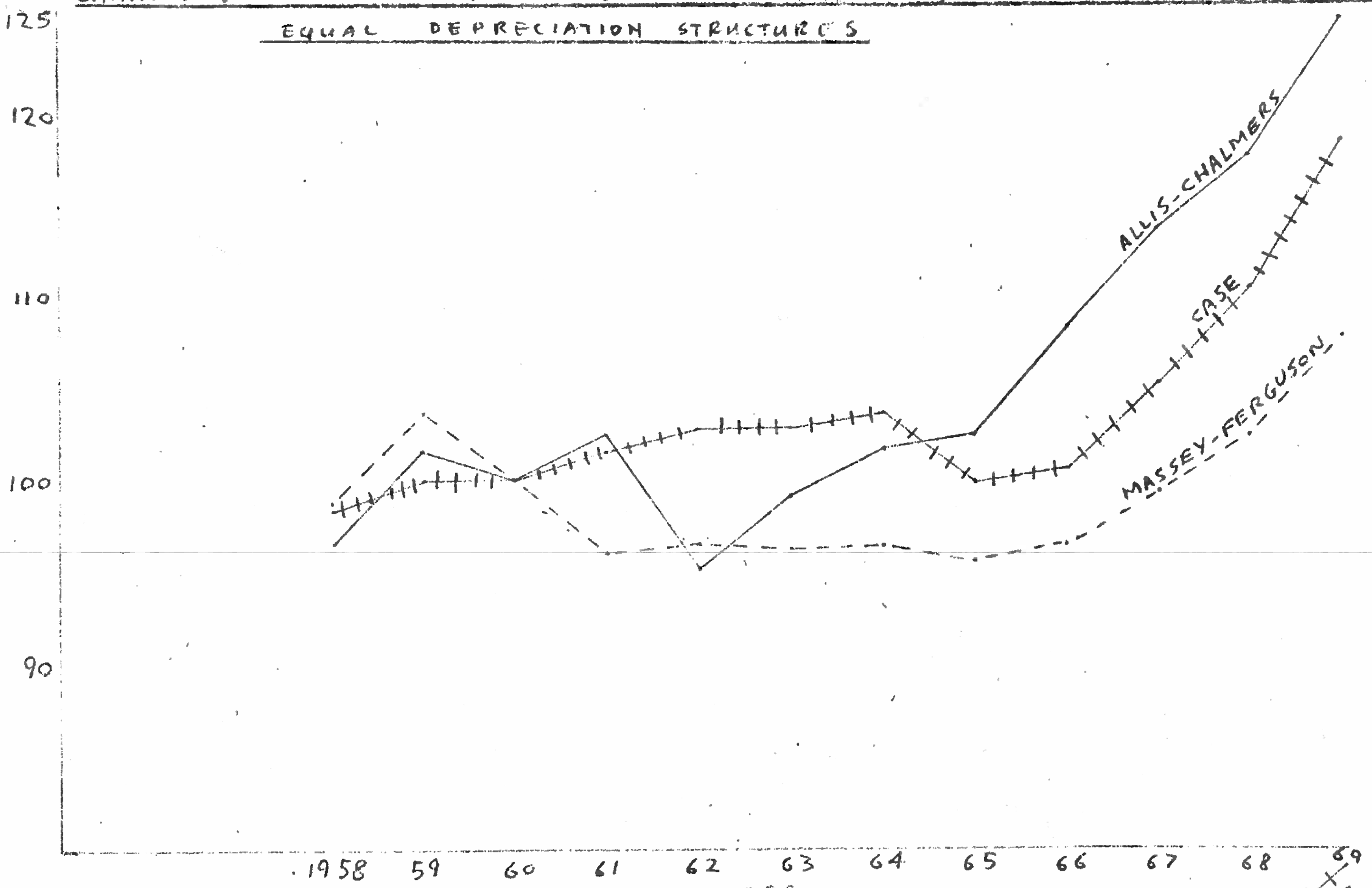

EQUAL DEPRECIATION STRUCTURES




EQUAL DEPRECIATION STRUCTURES

CHART 7 : EFFICIENCY CORRECTED (HEDONIC CONSTRAINT) PRICE INDICES FOR BRANDS

EQUAL DEPRECIATION STRUCTURES

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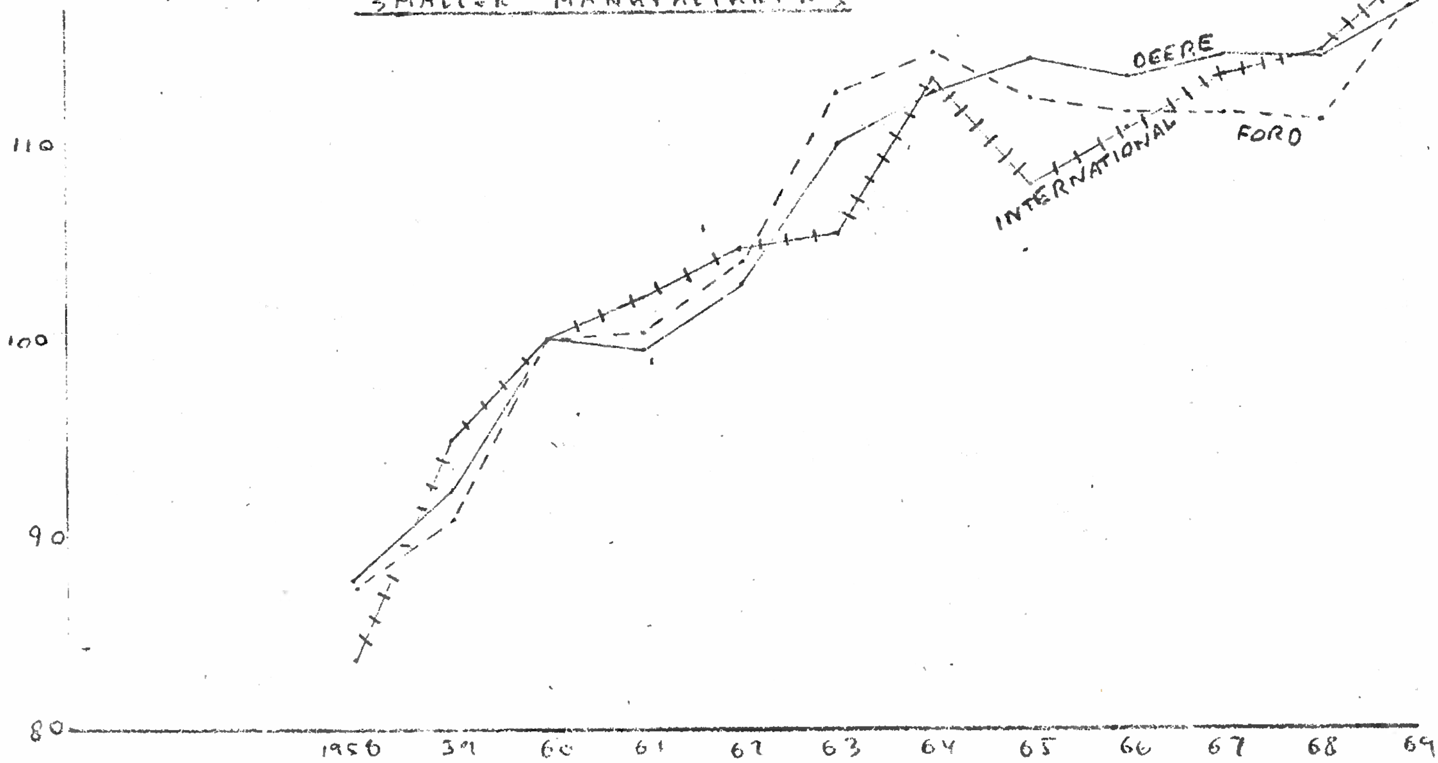


LARGER MANUFACTURERS

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