RESEARCH ON PRODUCT CHARACTERISTICS: MODELS, APPLICATIONS, AND MEASURES

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CONTENTS

SUMMARY

This report summarizes research on product characteristics and provides a bibliography. (Product characteristics are objective properties of products.) Its purpose is to facilitate and encourage further research on the economics of product characteristics. Study of product characteristics is relevant to various problems: quality, grades, standards, product differentiation, and technological change, among others.

The report presents a model of consumer behavior and a model of firm behavior, both of which lead to three hypotheses. (a) Price paid for a product equals the sum of the monetary values of the product's characteristics. Monetary value of each characteristic of a product equals the product's marginal yield of the characteristic multiplied by the marginal implicit price paid for the characteristic. (b) Demand for a product is a function of product prices and product characteristics. (c) Total demand for a characteristic depends upon prices of products containing that characteristic, or, alternatively, upon prices of product characteristics. Statistical studies that bear on these three hypotheses are summarized. Linear programming models of blending operations also are used to derive the hypotheses. Results of applying one of the programming models to corn-blending operations are used in an evaluation of corn grades. Work on accuracy of pricing of live slaughter cattle and hogs is reported. Pricing accuracy studies attempt to determine what prices "should be" from knowledge of a product's actual characteristics. Various applications of the two economic models of consumer and firm behavior are discussed.

A linear programming model of profit-maximizing firms is used for microeconomic evaluation of technical change. To select superior animals for breeding programs, animal breeders need measures of economic values of genetic traits. An application of sensitivity analysis to linear programming models of swine enterprises is used to obtain economic values of genetic traits in swine.

The definition and measurement of product characteristics is discussed. The final section of text presents sources of information on measures of characteristics of food products.

Research on Product Characteristics: Models, Applications, and Measures[1]

by George W. Ladd

For many economic problems, it is appropriate to assume product homogeneity. The essence of some problems, however, is product heterogeneity. Among the latter are problems described by the terms: quality, grades, standards, product differentiation, product development, and technological change. If one assumes product homogeneity, it is appropriate to use "product" as the basic unit of analysis. This will not do, however, if one is studying product heterogeneity. If one is dealing with product heterogeneity, it is fruitful to use "product characteristic" as the basic unit of analysis and to consider a product to be a collection of characteristics.

This report summarizes work on product characteristics. It summarizes a theory of consumer behavior and a theory of firm behavior that lead to verifiable hypotheses concerning: (a) relation of price of a product to characteristics of the product, (b) relation of demand for a product to characteristics of the product, and (c) demand for product characteristics. This report summarizes empirical studies that test these hypotheses. Fourteen applications of these models are presented: (a) analysis of market-shares, (b) evaluation of product grades, (c) definition of quality, (d) study of pricing accuracy, (e) blending problems, (f) component pricing of milk, (g) product design, (h) advertising, (i) price indexes, (j) allocation of bank credit, (k) spatial equilibrium, (l) impact of economic development on nutrition, (m) estimation of production functions, and (n) value of saving life. Microeconomic analysis of technical change is discussed. Much technical change involves changing the characteristics of products that are production inputs. Lastly, sources of data on characteristics of food products are presented.

OBJECTIVES

This report has two objectives. One is to stimulate further research on economics of product characteristics. The other is to help persons interested in working in this area by providing them a summary of relevant theory and empirical work and a list of readings they can turn to for more information. Many agricultural scientists besides economists are concerned with product characteristics: plant and animal breeders, with heritable characteristics; food technologists, with food or farm product characteristics; agricultural engineers, with characteristics of machinery and their effects upon characteristics of crops; agronomists, with grain characteristics, to name a few. By relating economics to product characteristics, it is hoped that this report will facilitate interdisciplinary research between economists and other agricultural scientists.

This report contains an extensive list of references, but no effort has been made to compile an exhaustive list. The list of references is intended to be a sufficiently large sample of the literature to provide examples of work in all areas of research on characteristics of agricultural products.

CONSUMER GOODS CHARACTERISTICS MODEL (CGCM) [2]

Model

The starting point for this model is the assumption that the enjoyment, or satisfaction, or utility, that a consumer obtains from a product is derived from the characteristics (objective properties) of the product. Products provide utility to a consumer because they provide characteristics. The total amount of utility a consumer obtains from his purchases of products depends upon the total amounts of product characteristics he obtains from his purchases of products. Let x_{0j} be the total amount of the jth product characteristic provided to the consumer by his consumption of all products. Let x_{ij} be the quantity of the jth characteristic provided by one unit of product i. For example, x_{ij} might measure the length of an automobile or the amount of meal preparation time saved by using a TV dinner. Let q_i represent the quantity of the ith product consumed. Then we can express total consumption of each characteristic as a function of quantities of products consumed and of characteristic input-output coefficients, x_{ij}. The consumer's utility function is expressed as

$$(1) \ U = U(x_{01}, x_{02}, ..., x_{0m}).$$

It is assumed that the consumer can vary only the q_i. The magnitudes of the x_{ij} are parameters to the

consumer; their magnitudes are determined by producers.

The consumer is assumed to maximize (1), subject to the budget constraint

$$(2) \; \Sigma_i p_i q_i \leq I$$

where p_i is the fixed price paid for the ith product, and I is his fixed money income. Consumption of negative quantities of products is not allowed.

$$(3) \; q_i \geq 0 \text{ for all } i$$

From the first-order conditions for maximization of (1) subject to (2) and (3), several relations can be established, of which these are important for present purposes:

$$(4) \text{ If } q_i > 0, \text{ then}$$

$$(5) \; p_i = \Sigma_j (\partial x_{0j} / \partial q_i) (\partial I / \partial x_{0j})$$

$$(6) \text{ If } p_i > \text{ right-hand side of (5), then}$$

$$(7) \; q_i = 0$$

$\partial x_{0j} / \partial q_i$ is the marginal yield of the jth product characteristic by the ith product. $\partial I / \partial x_{0j}$ is the marginal rate of substitution between total income (or total expenditure) and the jth product characteristic; it can be interpreted as the (marginal) implicit price for the jth product characteristic. Expressions (4) through (7) have reasonable economic interpretations.

Hypotheses

Hypothesis 1

According to (4) and (5), for each product consumed (i.e., for $q_i > 0$) the price paid by the consumer equals the sum of the marginal monetary values of the product's characteristics. The marginal monetary value of each characteristic equals the quantity of the characteristic obtained from the marginal unit of the product multiplied by the marginal implicit price of the characteristic. This relation will be referred to as CGCM Hypothesis 1. According to (6) and (7), if the price of a product exceeds the total marginal value of the product's characteristics to a consumer, the consumer does not buy the product.

Hypothesis 2

The x_{ij} are parameters to the consumer; they are, however, variables under the control of producers. From the analysis of the effect of variation in the characteristic input-output coefficients, CGCM Hypothesis 2 is derived. This hypothesis is: Consumer demand for a good is affected by characteristic input-output coefficients; i.e., by characteristics of goods, and by income and product prices.

Hypothesis 3

The total amount of characteristic j consumed is simply $\Sigma_i x_{ij} q_i$. From Hypothesis 2, then, CGCM Hypothesis 3a follows: The total demand for a characteristic depends upon income, product prices, and characteristic input-output coefficients. From this hypothesis and from relations (4) and (5), CGCM Hypothesis 3b can be derived: The total demand for a characteristic is affected by income, prices of product characteristics, and characteristic input-output coefficients. Whereas 3a involves prices of products, 3b involves prices of characteristics.

Statistical Analyses

A number of statistical studies consistent with CGCM hypotheses 1, 2, or 3 have been published.

Hypothesis 1

Dhrymes (1971) found that a large proportion of variance in U.S. automobile prices could be explained by a linear combination of automobile length, width, brake horsepower, number of cylinders, number of doors, and presence or absence of automatic transmission and power steering.

Ladd and Zober (1977) found that a large proportion of variance in prices of automobiles in the United States could be accounted for by a linear combination of width, height, curb weight, brake stop distance from 60 to 0 mph, fuel economy in miles per gallon, rear headroom, rear legroom, number of doors, presence or absence of fuel injection system, and country in which car was made. (Types of transmission and steering system were not included in their analysis because all cars they studied had the same type of transmission and the same type of steering.) The addition of four variables to the linear function—square of width, square of height, square of fuel economy, and square of rear headroom—resulted in small but statistically significant increases in the proportion of explained variance in prices.

Studies of fresh vegetable prices (Waugh, 1928, 1929), of fresh strawberry prices (Clarke and Bressler, 1938), and of egg prices (Perregaux et al., 1938) dealt with wholesale prices rather than retail prices. But because wholesale demand for these products is so closely related to retail demand, and wholesale and retail prices are highly correlated, their results are consistent with CGCM Hypothesis 1. These three studies will be discussed more fully in a later section on Neoclassical Input Characteristics Model: Statistical Analyses.

In a study of retail prices of 31 different meat, dairy, and poultry products, Ladd and Suvannunt (1976) found that these prices were significantly related to amounts of food energy, protein, carbohydrates, phosphorous, iron, potassium,

riboflavin, and ascorbic acid provided per pound. They used a linear function. Later analysis of their data showed that adding squared terms to their linear function resulted in an increase in the value of R^2 that was significant at the 5-percent level.

Musgrave (1969), Kain and Quigley (1970), and King (1976) have related prices of housing to housing characteristics.

Hypothesis 2

Brems (1951, pp. 34-46) computed the ratio between new Ford and Chevrolet registrations and found this ratio to be related to the ratio between their prices and the ratio between their brake horsepower.

Stone (1954, pp. 338, 393) tested the hypothesis that annual beer consumption is a function of beer strength. He used annual average gravity as a measure of strength and found a significant partial correlation between consumption and gravity.

Harrington and Gislason (1956) studied the effects of quality-appearance factors on retail sales of fruits. They found that sales of peaches were affected by percentage of peaches with extra color; sales of apricots were affected by percentage having extra color, percentage having moderate and severe defects, and percentage of hard apricots; and sales of cherries were affected by percentage of ripe cherries.

Ratchford (1975, p. 70) concluded from Lancaster's (1971) activity analysis of consumer behavior that "brand share models which do not take account of the absolute levels of prices or expenditures. . .may give misleading predictions." This hypothesis can be derived from CGCM Hypothesis 2, as can the hypothesis that market-shares are affected by product characteristics. A brand's share of the market is the ratio of its sales to the total of its own sales and sales of competitive brands. Hypothesis 2 states demand for one product as dependent upon input-output coefficients, product prices, and income. Brand-share can be be expressed as a ratio of one function containing these variables to the sum of several functions containing these variables, and hence, brand-share depends upon these variables.

Studies by Telser, Cowling and Cubbin, and Naumann et al. are consistent with this hypothesis on brand shares. Telser (1962) used annual time series data to study market-shares of cigarette companies. To allow for the introduction of filtered, mentholated, and king-sized cigarettes in the Post-World War II era, he introduced a product innovation variable into the equation for the market-share of each company. This variable was the ratio of an index of product-mix for the company to an index of product-mix for the entire industry. He found that the variable explaining most of the variations in market-share was the product innovation variable.

In a study of brand-shares in the United Kingdom car market, Cowling and Cubbin (1971) included car prices, car characteristics, and prices of car characteristics. Briefly stated, their model was

$$P_{it} = f(V_{it}) + u_{it}$$

$$q_{it} = g(u_{it} \, q_t, A_{it}, q_{it\text{-}1}, e_{it})$$

where

p_{it} = price of brand i at time t

V_{it} = vector of characteristics of brand i at time t

u_{it} = disturbance term

q_{it} = sales of ith brand in time t

q_t = total sales of all brands in time t

A_{it} = share of industry's total advertising expenditures by maker of brand i in time t

e_{it} = disturbance term.

The first expression relates brand price to brand characteristics. The disturbance term is positive for a "high-priced" car, that is for a car whose market price exceeds the estimated average monetary value of its characteristics, and is negative for a "low-priced" car. The second expression relates brand sales to this disturbance, advertising expenditure share, total sales of all brands, and lagged sales of brand i.

These two studies used time-series data. But the same hypotheses could be incorporated into a cross-section study of differences in brand-shares at a point in time. Each brand-share could be related to its own characteristics and to characteristics of other products. Such a study could be viewed as an extension of Anderson's (1974) controlled experiment to study effects of prices, trading stamp premiums, and shares of display space on market shares. This study, in turn, is an extension of work by Padberg et al. (1967) on relation of display space shares to market-shares.

Naumann et al. (1959) investigated retail sales of shank portion smoked hams, rib end loin roasts, and center-cut ham slices to determine effect of leanness of a cut on market-share of the cut.

CGCM Hypothesis 2 states that demand for a product is a function of product characteristics. One implication of this hypothesis is that demands for different, related, products can be expected to be different. In the previously cited studies, product demand was stated as a function of product characteristics. A number of studies have found differences in demand functions for similar products, but have not related these differences to differences in product characteristics. An example is Duewer's (ca. 1974) study of demand for retail cuts of pork. He estimated price-quantity relationships for each of eight cuts of pork at each of three types of outlets, for

a total of 24 relationships, and found different income, own-price, and cross-price elasticities. Other examples are provided by Raunikar et al. in their treatments of different cuts of beef and pork (1965, pp. 21, 23) and different sizes and grades of eggs (1965, p. 33), and by Purcell et al. in their treatment of processed and fresh peaches (1972, p. 10).

Some studies of demands for fresh fruits and vegetables differentiate among early-, mid- and late-season crops, or between spring and fall crops. Differences in seasonal demand functions may result from seasonal variation in characteristics of crops or from seasonal variation in demand for crops having constant characteristics.

Hypothesis 3

The only studies that I have seen that bear on CGCM Hypothesis 3 are studies of demand for housing by King (1976) and of household consumption of nutrients by Adrian and Daniel (1976). King assumes the consumer's utility function to be weakly separable, reflecting a utility tree in which housing is one branch. The housing characteristics he studies are structural features, interior and exterior quality, interior space, and site. Each of these, in turn, is a composite of specific features. For example, structural features combine insulation, number of garages and baths, and laundry facilities. The price variables in his demand functions are prices of these four characteristics.

Adrian and Daniel (1976) related household consumption of protein, carbohydrate, fat, vitamin A, calcium, iron, thiamine, and vitamin C to family income, size, place of residence, race, education of homemaker, and stage of household in the family life cycle. All F ratios were highly significant. Their demand equations for nutrients did not contain implicit prices of nutrients or prices of foods containing these nutrients, however.

In summary, the literature contains a number of studies that are consistent with CGCM hypotheses 1, 2, or 3. I have not found any studies that are inconsistent with these hypotheses.

Related Models

CGCM is similar to a model introduced by Houthakker (1951-52) and subsequently used by a number of people, e.g., Adelman and Griliches (1961) and Cowling and Cubbin (1971), as the theoretical basis for "hedonic price analysis." An extensive list of references to the hedonic price literature can be found in Griliches (1971). The main difference between Houthakker's model and CGCM is in the treatment of the x_{ij}. In Houthakker's model, these are variables to the consumer. The consumer selects the values of q_i and x_{ij} that maximize utility. In CGCM, the x_{ij} are parameters to the consumer. His only instruments for maximizing utility are the q_i. From this difference in assumptions there arise two differences in the hypotheses. (a) Expressions (4) and (5) and CGCM Hypothesis 1 impose a constraint of additivity on the relation of product price to product characteristics. Houthakker's model does not lead to this constraint, but only yields the hypothesis that a relation between product price and product characteristics does exist. Most empirical workers in the hedonic price field use logarithmic or semi-logarithmic relations between product price and characteristic input-output coefficients. (b) CGCM hypotheses 2 and 3 relate demand for products and demand for characteristics to characteristic input-output coefficients. Houthakker's model does not lead to the hypotheses of relations between demand and input-output coefficients.

CGCM is also similar to Lancaster's (1971) activity analysis of consumer behavior. The main differences between the two are these. (a) Lancaster assumes a linear consumption technology, whereas CGCM does not make this assumption. Lucas (1975, pp. 167-168, 176) has questioned the linearity assumption. (b) Lancaster assumes that marginal utilities of all characteristics are nonnegative. Hendler (1975) has questioned this assumption. CGCM does not make this assumption. (c) Both Lancaster and CGCM assume that utility is a function only of total quantities of characteristics consumed and is independent of the distribution of characteristics among commodities consumed. See Lucas (1975, pp. 167, 176) and Hendler (1975) for discussion and criticism of this assumption. The assumptions of CGCM can easily be relaxed, however, to allow utility to depend upon total quantities of characteristics and distribution of characteristics among commodities without destroying hypotheses 1, 2, and 3; see Ladd and Suvannunt (1976). The Lancaster, Houthakker, and Ladd and Suvannunt models state consumer utility as a function of product characteristics, where characteristics are defined as objective, universal properties of things. Some people object that utility does not depend upon characteristics so defined, but upon consumption services provided by characteristics. Ladd and Zober (1977) present a model that distinguishes between (objective, universal) characteristics and consumption services. In their model, utility depends upon quantities of consumer services. These quantities depend upon quantities of characteristics that, in turn, depend upon quantities of products consumed. Their model yields the same three hypotheses yielded by CGCM. It also yields a fourth hypothesis: For each product consumed, the price paid by the consumer equals the sum of the marginal monetary values of the product's contributions to various consumption services. The marginal monetary value of the product's contribution to a consumption service equals the product's marginal contribution to the

service multiplied by the marginal implicit price of the consumption service.

The distinction between characteristics and consumption services is similar to the distinction that Ohta and Griliches (1975) draw between a car's physical characteristics (e.g., horsepower, weight, and length) and performance variables (e.g., acceleration, handling, ride, frequency of repair). Ohta and Griliches regressed automobile prices upon measures of performance.

Ladd and Zober present a summary of the criticisms of Lancaster's model and a discussion of tests of these assumptions. Few empirical studies are completely consistent with these assumptions.

For a review and summary of the Lancaster model, see Ratchford (1975), Hendler (1975), and Haines (1975). For discussion of Lancaster and Houthakker, see Lucas (1975).

The regression method used by Ladd and Suvannunt (1976) to estimate prices of nutritional elements is not the only available method for computing prices of nutrients. Various people have used linear programs to determine minimum-cost diets for humans. The duals to such problems provide shadow prices of nutrients. See the later section on Blending Problems: Minimum-Cost Diet for further discussion.

NEOCLASSICAL INPUT CHARACTERISTICS MODEL (ICM)[3]

Model

Differences in yields of input characteristics affect producers because such differences result in different amounts of output from a given set of inputs. The starting point for this model lies in stating the amount of output as a function of amounts of input characteristics used. Consider a competitive multiproduct firm in which each production function is independent of other production functions. Let v_{ih} = quantity of ith input used in production of hth product, r_i = (fixed) price paid for the ith input, p_h = (fixed) price received for the hth output, q_h = quantity of the hth output, x_{jih} = quantity of characteristic j provided by one unit of input i used in production of product h, and x_{jh} = total quantity of characteristic j used in production of product h. Write the production function for product h as

$$q_h = F_h(x_{1h}, x_{2h}, ..., x_{mh})$$

Manipulating the first-order conditions for profit-maximization yields the expression

$$(8)\ r_i = p_h \sum_j (\partial F_h / \partial x_{jh})(\partial x_{jh} / \partial v_{ih})$$

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[3]For more complete discussion of the assumptions, analysis, and hypotheses, see Ladd and Martin (1976) and Martin (1974).

$\partial x_{jh} / \partial v_{ih}$ is the marginal yield of characteristic j to production of output h from input i. $\partial F_h / \partial x_{jh}$ is the marginal physical productivity of characteristic j used in product h. And $p_h \partial F_h / \partial x_{jh}$ is the value of the marginal product of this characteristic; it can be interpreted as the marginal implicit (or imputed) price paid for the jth characteristic used in production of output h. Write $p_h \partial F_h / \partial x_{jh} = T_{jh}$. Then (8) can be written

$$(9)\ r_i = \sum_j T_{jh}(\partial x_{jh} / \partial v_{ih})$$

An expression similar to (8) is obtained if the p_h and r_i are not fixed, but are instead functions of levels of output and inputs.

Hypotheses

Hypothesis 1

Expression (9) states that the price paid for each input used in producing output h equals the sum of the values of the marginal yields of the input's characteristics to the production of the hth output. ICM imputes values to input characteristics in the same way that CGCM imputes values to consumer goods characteristics.

Hypothesis 2

CGCM Hypothesis 2 related demand for consumer goods to characteristics of consumer goods. ICM Hypothesis 2 states that demand for productive inputs is affected by the characteristics of the inputs.

Hypothesis 3

ICM Hypothesis 3a states that total demand for an input characteristic is related to prices of inputs and outputs and to quantities of input characteristics per unit of input. ICM Hypothesis 3b states that total demand for an input characteristic is related to prices of input characteristics and outputs and to quantities of input characteristics per unit of input. The prices in 3a are product prices; the prices in 3b are prices of product characteristics.

Statistical Analyses

Hypothesis 1

A number of statistical studies are consistent with this hypothesis. The earliest one was Waugh's study (1928, 1929) of wholesale prices of vegetables. He found that substantial portions of the variances in wholesale prices of asparagus, tomatoes, and cucumbers could be accounted for by quality-appearance characteristics of the vegetables. He regressed the ratio of the price of each lot of a product to the season average price of the product on measures of product characteristics and converted the regression coefficients into prices of product characteristics. For

asparagus and tomatoes, he used a linear relation. For cucumbers, he found an equation containing linear terms and squared terms to be superior to a linear relation.

Two other early studies bearing on this hypothesis concern strawberry and egg prices. Clarke and Bressler (1938) found that prices of crates of strawberries were related to average size of berries, condition, uniformity, color, and variety. Average size and condition were the most important. The premium for a given size declined as the supply of that size increased. Perregaux et al. (1938) determined that between 76 and 97 percent of variance in prices of lots of eggs at different auctions at different times was accounted for by weight, grade, and color. Premiums for large eggs were related to supply of large eggs: the premium declined as the supply of large eggs rose.

Among the latest studies relating to this hypothesis is the Menkhaus and Kearl (1976) study of prices of 1,535 lots of cattle sold at feeder sales in Worland, Wyoming, in 1973 and 1974. Prices for steers were significantly higher than for heifers. Prices for Hereford, Angus × Hereford crosses, and Charolais crosses were not significantly different in either year. Prices for Hereford and Angus × Hereford crosses were significantly higher than Angus prices in both years. Prices for Charolais crosses were significantly higher than prices for Angus in 1974, and were higher but not significantly so in 1973. Price per 100 pounds rose by 22¢ in 1973 and 16¢ in 1974 for each one-animal increase in lot size. In 1973, price fell by $2.99 per hundred pounds for each 100-pound increase in weight. In 1974, however, the effect of weight on price was not significant. Menkhaus and Kearl attributed this difference to changes in relative prices of feed and of feeder cattle between 1973 and 1974. In 1974 feeder cattle prices were lower and feed prices were higher, and buyers could buy additional weight of heavy animals for less than the cost of putting additional weight on lighter animals. This increased the relative value of heavier animals to the buyers.

Results obtained in a study of prices of 2,304 feeder cattle sold at six auctions in Nebraska and Kansas in November and December of 1972 (North Central Regional Livestock Marketing Research Committee, 1975) were in general agreement with these results. The study found: (a) Steer prices were higher than heifer prices. (b) Prices for Hereford and Angus × Hereford crosses were not significantly different. (c) Prices for Hereford and Angus × Hereford crosses were significantly higher than Angus prices. (d) Prices for Charolais differed little from prices for Angus. (e) Price per pound rose as lot size increased. (f) Price fell as weight increased, but the estimated relationship was not linear. For example, steer price fell by $2.81 per hundred pounds as weight rose from 450 to 550 pounds, but only fell by $1.36 per hundred pounds as weight rose from 650 to 750 pounds.

The breeds arranged in order from lowest to highest price were dairy breeds, Shorthorn, Angus, Charolais, Okie No. 1, "other," Hereford × Angus crosses, and Hereford. Price was positively correlated with grade. A lot of cattle that came directly from a farm or ranch was classified as "fresh." A lot that was being resold after a recent purchase was classified as "trader." Trader cattle sold for slightly less than fresh cattle. Under-filled (shrunk-out) cattle sold for a $0.91 premium relative to normally filled cattle. Over-filled cattle sold for $0.77 less than normally filled cattle. Thin cattle brought a premium of $0.78 per hundred pounds over cattle of normal fleshiness. Fleshy or relatively fat cattle brought a slightly (nonsignificantly) smaller price than normal cattle. Presence or absence of horns had a negligible effect on prices. Prices did differ among auction locations. There was a statistically significant tendency for lots sold later in a sale to bring higher prices than lots sold earlier in a sale.

This study is of interest because of procedural as well as substantive reasons. Not only were classifications—location, sex, breed—measured by dummy variables, but dummy variables were also used for the continuous variables—weight, size of lot, time of sale when lot was sold. This procedure was also used by Madsen and Zeng (1971), who discuss the use of the dummy variable model in detail.

In a study of prices at feeder cattle auctions in Arizona in 1969, Menzie et al. (1972) also found prices to be significantly related to sex, breed, grade, and number of animals in lot. They also found feeder cattle prices to be related to fat cattle prices. Prices of both sexes fell as weight rose, but the price decrease was more rapid for steers than for heifers and was more rapid at the lighter weights than at the heavier weights for both sexes. As a result, the steer-heifer price differential was less at heavier than at lighter weights. The steer-heifer price differential rose and fell as fat cattle prices rose and fell.

In a study of prices at cooperative feeder-cattle auctions in Michigan in 1966 and 1967, Cole (1969) found that prices were related to sex, grade, lot size, and weight. In an earlier study of prices of feeder cattle in Virginia, Williamson et al. (1961) found prices to be significantly related to size of sale (number of head sold), size of lot, average weight of animals in lot, breed, and grade.

Johnson (1957) and Stout and Freund (1958) reported results of analyses of prices of 88 thousand slaughter animals sold at auctions in 1953, 1954, and 1955. Some 70 percent of the variance in the prices of the animals was explained by a linear function of grades of animals (ranging from 1 for top prime to 21 for low cutter), estimated dressing percentage, liveweight of animal, size of market, and seasonal effect. Prices were also related to breed-type (dairy, beef, or mixed breed), sex, and area. The same data were also analyzed by Freund and Purcell (1959) to

investigate influences of marketing conditions and market management practices on prices.

Berry et al. (1965) found that prices of fertilizer were linearly related to amounts of nitrogen, K_2O, and P_2O_5 in the fertilizer and were related to characteristics of buyers (their deliberativeness and knowledge) and to market characteristics (number of sellers, cooperative influence). Griliches (1958, p. 599) found that 95 percent of the variance in national average prices per ton of mixed fertilizer could be accounted for by a linear function of the amounts of N, P_2O_5, and K_2O per ton.

Results of a study of 19 tests covering 13 years of boar testing at the Georgia Swine Testing Station (Neville et al., 1976) are consistent with Hypothesis 1. In this study, final age (age at which boars reached 90.7 kg. of weight or 150 days of age, whichever was attained first), average daily gain, feed efficiency, backfat thickness, and size of litter in which boar was born were significantly linearly related to prices of Duroc, Hampshire, and Yorkshire boars sold by the testing station. The results indicated a tendency for heavier boars to bring higher prices. Variation in boar prices among sale dates was significantly affected by variations in slaughter hog prices.

Hyslop (1970) analyzed prices of hard red spring wheat. He found that a large proportion of variance in prices could be explained by a linear combination of percentage dockage, protein content, test weight, percentage damaged kernels, percentage of foreign material, percentage of shrunken and broken kernels, area of origin, destination, and transport mode.

Fettig (1963) found that U.S. farm tractor prices were related to type of engine (diesel or other) and to horsepower. Cowling and Rayner (1970) found that a similar relation accounted for a substantial portion of variance in United Kingdom prices of farm tractors.

A study by Wachtel and Betsey (1972) found that an employee's annual wage earnings were linearly related to the employee's years of experience in the present job, race, sex, age, years of education, and marital status. Many other studies have found earnings to be related to employee characteristics (see, e.g., Mincer, 1974, Johnson and Stafford, 1974, Malkiel and Malkiel, 1973, and Griliches and Mason, 1972). But their results cast no light on Hypothesis 1 that price is equal to the sum of the products of marginal yields of characteristics and marginal implicit prices because they used semilogarithmic equations.

In summary, a large number of studies are consistent with Hypothesis 1: I have found none inconsistent with this hypothesis.

Hypothesis 2

Many studies deal with Hypothesis 1; few deal with Hypothesis 2. The ones that do are consistent with the hypothesis. Johnson (1976) studied rail transportation of grain from Michigan grain elevators. The quality variables or product characteristics that he considered were truck equipment delay (average days of delay in delivery of motor trucks), rail equipment delay (average days of delay in delivery), damage by truck (average value of damage in truck transit per $1,000 value), damage by railroad (average value of damage in rail transit per $1,000 value), and average railroad speed. He concluded that the quantity of railroad services demanded by an elevator is influenced by the delay in delivery of rail cars, damage by railroad shipment, and promotional efforts by trucking firms, as well as by characteristics of the elevator. He also concluded that the ratio of rail shipments to truck shipments by an elevator is related to truck equipment delay and railroad speed as well as to characteristics of the elevator.

ICM Hypothesis 2 states that demand for an input is a function of input characteristics. One implication is that demands for different, but similar, inputs can be expected to be different. Some studies have found differences in demands for similar inputs, but have not related these differences to differences in input characteristics. Examples are the Matsumoto and French (1971) study of brussels sprouts demand and the Abaelu and Manderscheid (1968) study of green coffee demand. Abaelu and Manderscheid (1968) estimated separate green coffee demand functions for different varieties of coffee. They found that price and income flexibilities varied by variety of coffee. Matsumoto and French (1971) studied demand for brussels sprouts. They had six brussels sprouts products (three different sizes of sprouts, and two different containers) and estimated a separate demand function for each of the six products.

Another implication of ICM Hypothesis 2 is that a brand's or firm's share of market is related to input prices and input characteristics. Results obtained by Cowling and Rayner (1970) in their study of market-shares in the United Kingdom tractor market are consistent with this hypothesis.

Hypothesis 3

Two studies of tractor demand relate to this hypothesis. Fox (1966) found that demand for tractor horsepower in the United States was related to tractor prices and stock of horsepower on farms, among other variables. This study is related to 3a. Rayner and Cowling (1968) found United States and United Kingdom demands for tractor horsepower were related to prices and stocks of tractor horsepower. This study is related to 3b.

Griliches' work (1958) on fertilizer demand also is consistent with Hypothesis 3b. The dependent variable in his demand function was total plant nutrients used; i.e., the sum of the amounts of N, P_2O_5, and K_2O used. His price variable was the price per unit of plant nutrient.

In summary, all the studies that I have found that relate to ICM Hypotheses 1, 2, or 3 are consistent with the hypotheses.

LINEAR PROGRAMMING INPUT CHARACTERISTICS MODEL[4]

The neoclassical ICM applies to any firm having independent production functions. Application of duality relationships to linear programming statements of blending problems provides an alternative derivation of ICM hypotheses and a method of assigning monetary values to characteristics of inputs used in blending problems. Martin (1974) and Ladd and Martin (1976) discuss two different blending problems. One is the problem of blending ingredients purchased at fixed prices to minimize the ingredient cost of one unit of output when each unit of output must possess (at least) minimum or (at most) maximum amounts of various characteristics. As is well known, the dual to such a problem provides shadow prices of the restricted characteristics. These shadow prices correspond to the values of the marginal products in the neoclassical ICM.

Their second linear program concerns a firm that possesses stocks of inputs of various characteristics, and the amounts of each characteristic on hand are known. The firm blends its stocks of inputs to produce various outputs. Each output must satisfy maximum or minimum limits on the amount of each characteristic. The firm blends its inputs to produce the amounts of various outputs that maximize its profit. The dual to this problem also provides shadow prices of the various characteristics. Ladd and Martin (1976) applied the second linear program to determination of optimum use of four carloads of corn actually shipped from a central Iowa elevator in the fall of 1971 by a firm selling five products: No. 1 through No. 5 corn. They also solved several other blending problems. Results are presented in detail in Martin (1974) and are summarized in Ladd and Martin (1976). (Martin's presentation of results contains some errors. These are corrected in Ladd and Martin.)

Westgren and Schrader (1977) have pointed out that Ladd and Martin's second linear program contains the unrealistic assumption that any amount of a characteristic of corn can be removed from a bin or carload without affecting the amounts of other characteristics remaining in the bin or car. They present a superior formulation of the blending problem for multiproduct firms. Ladd (1977b) also discusses the Westgren and Schrader model.

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[4]For more complete discussion see Ladd and Martin (1976) and Martin (1974).

APPLICATION OF CGCM AND ICM TO GRADES AND STANDARDS

These two models have implications for definition and measurement of quality and have application to evaluation of grades and standards.

Quality

These models lead to the same conclusion that Southworth reached. He wrote (1961, p. 1385), "Webster's first definition of 'quality' makes it synonymous with 'characteristic.' Quality meaning 'superior quality' is a derived or secondary meaning. Quality, then, need not be ordinal—good, better, best. It may only be different." These two models lead naturally to the idea that we measure a product's characteristics to measure its quality. Then the idea of "product quality" is replaced by "product qualities," and "qualities" are measured by measuring characteristics. Then it can easily happen that it will not be possible to rank two products according to their "quality" because one product will be of higher "quality" according to one characteristic, but the other product will be of higher "quality" when ranked according to the other characteristic. Then all that can be said is that the two products are of different qualities. We might draw an analogy between "quality" and vectors. Just as we may have two products that are of different qualities, though neither is superior to the other, we may have two vectors that are unequal though neither is greater than the other.

A problem with using "quality" in an ordinal sense is that "high quality" can mean different things to different users of a product. Corn can be high quality for cattle feeding but low quality for a wet miller.

This view of quality is contrary to Maynes' (1975) view. Maynes not only argues that it is meaningful to measure quality, but he presents a scalar, cardinal measure of quality of consumer goods. His measure of the quality of the jth product as assessed by one individual is

$$\Sigma_k W_{kj} C_{kj} / \Sigma_k W_{kj}$$

where W_{kj} is the weight assigned to the kth characteristic of product j, and C_{kj} is the characteristic score assigned to the kth characteristic of product j. He presents (1975, p. 543) two different measures of weights W_{kj}. For criticisms of Maynes' position that quality does have a scalar, ordinal measure and for criticism of his measure of quality, see the papers by Juster (1975) and Triplett (1975).

Application of ICM to Corn Grades[5]

For a specified list of product characteristics, define a grading system to be sign-optimal for a given firm with respect to that list if, for every characteristic, varying the yield of the characteristic per unit of product has the same effect on grade as on per-unit value of the commodity to the firm. Ladd and Martin present three pieces of evidence to support the conclusion that the present corn-grading system is not sign-optimal. One piece is their solutions to several corn-blending problems. As mentioned previously, however, Westgren and Schrader (1977) have shown that the Ladd and Martin shadow prices are of little use for evaluation of grades. See Ladd (1977b) for further discussion.

The second piece of evidence that Ladd and Martin use to show that the present system is not sign-optimal is Knapp's (1969) study. He made a linear programming study of the corn-blending and merchandising operations of an Iowa grain marketing cooperative. From his results, it is possible to compute the marginal value product (MVP) of each of the cooperative's 190 bins of corn. The MVP for a bin of corn equalled the maximum price that the cooperative could afford to pay for corn having the same characteristics as the corn in the bin. The results show a number of violations of sign-optimality. For example, the highest MVP's for a bin of No. 3 grade corn exceeded the lowest MVP's for bins of No. 2 grade corn and No. 1 grade corn (the highest grade). The firm could afford to pay more for some No. 3 corn than for some No. 1 and No. 2 corn. These linear programming results recall Southworth's statement about "quality" only meaning "different," and not having an ordinal meaning. Their third piece of evidence is survey data from users of corn on the relative importance of various attributes of corn.

Ladd and Martin suggest replacing the present numerical grades for reporting corn quality by a "specified-order method" of reporting. Under this system, each of the characteristics used in grading corn would be reported in a specified order. This method comes closer to achieving sign-optimality than any system of numerical grades. It allows each potential buyer to apply his own weight (or price) to each one of the characteristics.

Hoffman and Hill (1976) review the history and development of U.S. grades and standards for grain. The current U.S. standards for grain are published in a United States Department of Agriculture (1975) publication.

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[5]For a more complete discussion, see Martin (1974) and Ladd and Martin (1976).

Pricing Accuracy

During the 1950s and 1960s, numerous researchers studied accuracy of pricing of livestock. Pricing accuracy studies are similar to those studies of livestock prices cited in the section on Neoclassical ICM, Statistical Analyses, Hypothesis 1. There are important differences, however. Those studies on Hypothesis 1 relate market prices at one level of the marketing channel to characteristics of products at that same level of the channel. Pricing accuracy studies are concerned with interrelations between prices at two or more levels of the marketing channel and characteristics at two or more levels. Studies bearing on Hypothesis 1 relate to prices actually paid for purchased inputs. The work on pricing accuracy concerned determination of the maximum amount a packer could afford to pay for an animal.

Evaluation of accuracy of live animal pricing involves evaluation of accuracy of several steps: (a) predicting characteristics of the carcass from knowledge of characteristics of the live animal, (b) predicting yield of salable product from knowledge of the characteristics of the carcass (these first two steps may be combined into one), (c) selection of appropriate prices to apply to the salable product obtained from the carcass, and (d) determination of costs of slaughtering and cutting.

One of the earliest, and most frequently cited, studies of pricing accuracy dealt with hog prices (Engelman et al. 1953). In this study, each of 32 lots of hogs was priced in three ways: (a) a flat price for all animals within each live animal weight group, (b) live grading, and (c) carcass weight and grade. After slaughter, each carcass was cut into wholesale cuts and trimmings. Wholesale prices of the cuts and trimmings were used to determine wholesale value of each carcass. Deduction of packer's cost from wholesale value of carcass determined value of hog. If the value of a hog differed from price paid, a "pricing error" occurred. Pricing errors were smallest for carcass weight and grade pricing, and largest for flat pricing within each weight group.

Ikerd and Cramer (1968) developed the concept of "price signal refraction" in a study of hog prices. They defined price refraction as "the failure of differences in prices received at the wholesale level for pork carcasses of various weights and backfat thicknesses to be accurately reflected in price differentials paid at the live hog market level" (1968, pp. 225-226). They defined the absence of refraction as being characterized by equal net packer margins for all weights and grades of hogs. Thus, they defined "accurately reflected" to mean "equal net margins." They concluded that price refraction attributable to weight variations was small and insignificant, but

price refraction attributable to variations in backfat thickness was large and significant.

In a later study, Ikerd and Cramer (1970) developed a method for pricing pork carcasses and hogs by relating carcass value per cwt. of carcass to average backfat thickness; weight; average carcass value per cwt. of all carcasses; and price differentials between light and heavy hams, light and heavy loins, and light and heavy bellies.

Hayenga (1971) found that 72 percent of the variance in hog carcass value per cwt. liveweight was explained by slaughter weight, dressing percentage, and backfat. He also found that 69 percent was accounted for by backfat thickness, carcass length, loin eye area at tenth rib, and carcass weight.

For more extensive lists of references, further discussion, and summaries of pricing accuracy studies, see Stout and Thomas (1970), Schneidau and Armstrong (1970), and Williams and Stout (1964, pp. 681-698).

OTHER APPLICATIONS OF CGCM AND ICM

Two applications of CGCM and ICM were discussed in previous sections on Statistical Analyses. Hypothesis 2 was applied to analysis of market-shares, and Hypothesis 3 was applied to analysis of demand for product characteristics.

Blending Problems

In a blending problem, ingredients having various combinations of characteristics are to be blended together to obtain a product whose characteristics satisfy a set of restrictions. Linear programming has been frequently used to solve such problems. Kramlich et al. (1973, ch. 8), for example, discuss the use of linear programming to obtain least-cost mixes of ingredients for sausages. Arbuckle (1972) discusses the use of linear programming to obtain the least-cost combination of ingredients for ice cream mix.

Minimum cost diet

Various people have used linear programs to determine minimum cost diets for humans. See, for example, Smith (1959, 1963). The variables whose values are determined by the solutions to these programs are the amounts of various food items (e.g., enriched white flour, nonfat dry milk, lima beans, ground beef) to be used. The duals to such problems provide shadow prices of nutritional elements. Three observations in relation to these programs are in order: (a) They provide "minimum-ingredient-cost diets" and may or may not provide "minimum-cost diets." The only costs they include are costs of items used in the diet. They do not include costs for the energy and the cook's time used in preparation. (b)

Knowledge of these solutions is like having a list of the ingredients required for a recipe, but not having instructions for mixing, blending, warming, cooking, and serving. These solutions still leave the cook the sizable challenge of finding or creating recipes for preparation of the ingredients. The magnitude of the challenge is increased by the nature of the list of foods contained in the solutions to most such problems. (c) The solutions provide a bland, monotonous diet unless specific constraints are incorporated into the problem to assure some variety and improved palatability.

It is possible to formulate linear programs that do not have these three features. To do so, define each activity to be the number of servings of a certain dish or recipe (e.g., the number of hamburger sandwiches, the number of bowls of vegetable soup, the number of servings of tuna casserole). The cost of one unit of an activity can then be defined in either of three ways: (a) as the cost of the ingredients (e.g., the cost of the ground beef, of the bun, and of the condiments used to make one hamburger sandwich), or (b) as the cost of the ingredients plus the cost of utilities used in mixing and cooking one serving, or (c) as the cost of ingredients plus cost of utilities used in preparation plus a charge for the cook's time. Hall (1977) used this approach in her linear programming study of menu-planning. In some problems, she minimized food cost. In one problem, she minimized cost of food and energy used in cooking.

Grain blending

The previous section on Application of ICM to Corn Grades discussed application of linear programs of corn-blending problems to evaluation of corn grades. References cited there were Knapp (1969), Martin (1974), Ladd and Martin (1976), Westgren and Schrader (1977), and Ladd (1977b). Schruben (1968) presents two corn-blending problems. In one, the corn merchandiser must determine which lots of corn to buy and what grades of corn to sell to maximize profit. The second problem is a combination of this blending problem and a transportation problem.

Schruben (1967), Niernberger (1970, 1973), Niernberger and Phillips (1972), and Niernberger and Ward (1973) apply linear programming to wheat blending and flour milling. Schruben (1967) discusses the use of linear programming to obtain a maximum profit solution to the problem of selecting wheats to satisfy product restrictions. Niernberger (1970) describes a programming technique for combining individual flour mill-streams to obtain grades of flour demanded by customers. Niernberger and Phillips (1972) present a procedure that can be used by grain and flour-milling firms that blend wheats to be used in manufacturing flour. Niernberger (1973) and Niernberger and Ward (1973) use programming to determine wheat mix for white pan-bread flour.

Livestock and poultry rations

Linear programming has been widely used for determination of rations for livestock and poultry. Some programs determine the ingredients to be used to minimize the cost per unit (ton or hundred pounds) of feed that satisfies specified nutritional restrictions. In one such formulation, Katzman (1956) determined the ingredients to use to obtain 100 pounds of poultry feed at least cost. He considered 8 ingredients: wheat bran, oats, 44% soybean oil meal, fish meal, 50% meat and bone scrap, steamed bone meal, corn, and wheat standard middlings. Each 100 pounds of feed was required to contain at least 20 pounds of crude protein, 1.0 pound of calcium, 0.6 pound of phosphorous, 1.0 pound of arginine, 0.9 pound of lysine, and 0.25 pound of tryptophan and was required to contain not more than 4.0 pounds of fiber. Twelve other nutrients are required in poultry feed, but Katzman excluded these from the linear program because most poultry feed mixtures that meet the listed nutritional requirements also contain the required amounts of these 12 nutrients. Using December 1952 Chicago wholesale prices, he found that the way to meet the nutritional requirements at least cost was to use 49 pounds of corn, 13 pounds of wheat bran, 35 pounds of soybean oil meal, and 3 pounds of steamed bone meal.

Alternatives to minimizing cost per unit of feed are to minimize cost per unit of gain or to maximize net revenue. Dean et al. (1969) formulated a linear program for determining rations for dairy cattle to maximize income above feed cost. The program determines: (a) mix of concentrates, (b) mix of roughages, (c) roughage-concentrate ratio, (d) levels of feeding, and (e) quantity of milk production, that maximize income above feed cost.

Lofgreen and Garrett (1968) developed a net energy system for beef cattle in which net energy requirements and feed values are separated into net energy for maintenance and net energy for gain. Requirements for maintenance must be met before reproduction or growth is possible. Net energy required for maintenance depends upon sex and weight. Net energy requirements for gain depend upon sex, initial weight, and gain in weight. This system is discussed in National Academy of Science-National Research Council (1970). Brokken (1971a, 1971b, 1971c) presents linear programs that use the net energy system in determining least-cost beef rations under conditions of thermal neutrality and under environmental stress. Williams (1975), Williams and Ladd (1976), and Ladd and Williams (1977) combine the Brokken model with a Bayesian model for decision-making under uncertainty about future fed-cattle prices. Their procedure provides answers to the questions: (a) Should cattle be fed? (b) If so, how long should they be fed? (c) What rate of gain should be achieved? (d) What ration should be fed? The objective of their procedure is to maximize expected net income.

Some books on feeds and feeding discuss the use of linear programming to determine rations. Among them are books by Høglund et al. (1959, ch. 19); Schaible (1970, part 2); McCullough (1973, ch. 8); and Cullison (1975, ch. 49).

Component Pricing of Milk

Jacobson and Walker (1973) applied Hypothesis 1 to farm pricing of milk. They propose relating producer price per cwt. of milk to the amounts of fat solids, nonfat solids, and fluid in the milk. Their paper is one of the more recent in a long line of papers that relate to multiple-component pricing of milk. Another recent paper on this topic is by Stewart Johnson (1973). (The issue of the journal that contains the Johnson paper contains other articles on variability in milk composition.) Reports by Clarke and Hassler (1953) and by LeBaron and Brog (1968) also deal with this topic.

Product Design

ICM Hypothesis 2 and CGCM Hypothesis 2 are relevant to questions of product improvement, new product development, and product line selection. The model that was used by Cowling and Cubbin (1971) to study brand-shares in the United Kingdom car market, and that was discussed in the previous section on CGCM Statistical Analyses Hypothesis 2, could be used to study effect of product design on brand-share. Dorfman and Steiner (1954) dealt with a product having only one quality characteristic that affected demand. They determined conditions for optimal level of advertising and optimal level of quality (amount of characteristic per unit of product). Benson and Pilgrim (1961) determined the time-temperature integral at which pork and gravy should be processed to maximize consumers' ratings of palatability. If a product has two or more characteristics that affect demand in known ways, a generalization of the Dorfman-Steiner or Bensn-Pilgrim analysis can be used to determine optimal amount of each characteristic per unit of product. (See Ladd and Zober, 1977, for fuller discussion.)

Ladd and Martin (1976) applied ICM to the problem of optimal quality for a competitive firm. The firm could not affect the price it received by varying the amount of its output, but could affect price by varying the amounts of various characteristics in each unit of output. Studies aimed at determining weight and grade for marketing slaughter hogs or cattle deal with this problem. The profit-maximizing amount of each characteristic per unit of output is achieved when the effects of a one-unit variation in the amount of characteristic upon product price and upon average production cost are equal.

Kendrick and Hassler (1968) used a simple linear program to study standardization of green

hams. Standardization of hams may involve drying or adding water; adding salt; and trimming bone, skin, fat, or lean meat. These trimmings can be transferred to other products. They used linear programming to determine ways of standardizing to various standards that would maximize profit.

Matsumoto and French (1971) carried out a price discrimination analysis of the market for brussels sprouts. Their analysis did not concern product design, but did concern determination of amounts of each of six well-defined brussels sprouts products to sell. The six products were obtained by considering each combination of three sizes of sprouts (small, medium, and large) and two types of container (retail and institutional). The size distribution may be varied by varying the time interval between harvest or the timing of once-over machine harvest. They estimated costs of producing each size and of processing each size and each type of container. They estimated a separate demand function for each of the six products and then determined the distribution of sprout size and type of pack to maximize the industry's net revenue for 1961-62.

Advertising

Many advertisements concentrate on one or two of a product's outstanding characteristics. CGCM and ICM provide insight into such advertisements by providing a rule that can be used to allocate advertising expenditures. Suppose a firm's product has a number of different characteristics that can be advertised and the firm wants to decide how much to spend on advertising each characteristic and what price to charge to maximize its profit. Assume that the characteristics of the product are fixed. Let a_i represent the amount spent on advertising the ith characteristic. Define advertising elasticity of demand for characteristic i as $e(i) = (\partial q / \partial a_i)(a_i/q)$. From the first-order conditions for profit-maximization one obtains

$a_i/a_j = e(i)/e(j)$ for all i and j

The ratio between advertising expenditures on characteristics i and j equals the ratio between advertising elasticities of demand for the two characteristics. Thus, if customers are believed to be highly responsive to advertising of characteristic i [e(i) positive and large] and quite unresponsive to advertisement of characteristic j [e(j) positive but small], then the firm's expenditures on advertising characteristic i will be much larger than the firm's expenditures on characteristic j.

Another application of the product characteristics concept to advertising comes from treating an advertisement as a product and considering the design of the advertisement. "One of the most widely used indices of the attention value of published advertisements is the extent to which people read

and remember, as determined by readership recognition surveys . . . . In these surveys a representative sample of a publication's circulation . . . is interviewed shortly after publication of the survey issue . . . the interviewer goes through the issue page by page recording the elements which the respondent says he has read. The resulting readership scores are simply percentages of readers who report having read a particular article or advertisement" (Twedt, 1952, p. 207). Characteristics of printed advertisements can be classified into two groups: mechanical variables and content variables. Examples of the former are size of ad, number of colors, number of separate illustrations, number of type sizes used, largest sized type used, Flesch readability score. Examples of the latter are number of product benefits in ad, number of product facts, number of pictures of product in use. Twedt (1952) related readership scores to mechanical and content variables and found that between 34 and 64 percent of the variance in readership of ads in six different magazines could be accounted for by three mechanical variables: size of ad, number of colors, and square inches of illustration.

Hendon (1974) used 21 mechanical and 6 content variables to predict the percentage of people who remembered seeing an outdoor advertising message. The predictive ability of his regression equations was too low to be of value to advertisers. He attributed the low predictability to the fact that the simplicity of the outdoor medium caused the variables to have little variation. In another paper, Hendon (1973) summarizes numerous studies carried out over the last 50 years on variables affecting advertisement readership and perception.

Constant-Quality Price Indexes

Conceptually, an observed rise in price of a product over a period of years may be divided into two parts: change in price for product of a given quality and changes in price resulting from changes in product quality. The change in price of product i may be expressed as $dp_i = dp_i' + \Sigma_j (\partial p_i / \partial x_{ij}) dx_{ij}$, where dp_i' is the price change that would have occured in the absence of quality changes and the second term on the right-hand side represents price change due to quality changes. The p_i (or dp_i) are the prices used in government-sponsored price indexes such as the consumer price index or index of prices paid by farmers. If one has observations on the p_i and x_{ij} for some base period, one can estimate the $\partial p_i / \partial x_{ij}$, and these can be combined with observed values of dx_{ij} to compute a constant-quality price index.

For more discussion of constant-quality price indexes for consumer goods, see Adelman and Griliches (1961). The consumer price index for new

automobiles rose by 32 percent from 1950 to 1960. According to their constant-quality price index, the price of an automobile of constant quality only rose by 12 percent during this same period. Ohta and Griliches (1975) present recent work on constant-quality price indexes for cars.

Fettig (1963) and Rayner (1968) have computed constant-quality price indexes for farm tractors. Rayner and Lingard (1971) present a constant-quality price index and a variable-quality quantity index for British fertilizer use. Musgrave (1969) has computed a constant-quality price index for new single-family houses.

Allocation of Bank Credit

Harris (1973) has used an asset-characteristic model to analyze the role of nonprice terms in the allocation of bank credit. Each bank asset has price characteristics and nonprice characteristics. The price characteristics contribute to the bank's profit; the nonprice characteristics contribute to the soundness of the bank's portfolio. The bank selects its portfolio of assets to maximize its profit subject to a soundness constraint. His analysis yields a theoretical justification for the use of nonprice adjustments in the allocation of bank credit. For further discussion of Harris's model, see Ostas (1976) and Harris (1976).

Spatial Equilibrium

Many spatial equilibrium or temporal equilibrium studies have been carried out by agricultural economists. Almost invariably they have assumed product homogeneity. An exception is a study of the Australian sugar cane processing industry (Ryland and Guise, 1975). This study considered a cartel-type processing industry producing a standard final product from a raw material whose quality varies seasonally and geographically. Quality was simply the sugar content of sugar cane. An activity analysis model was developed to determine optimum period of production at a chain of sugar cane processing plants and to determine optimum regional flows of sugar cane and raw sugar. The results suggested that taking explicit account of raw material variability leads to higher net revenues than is obtained by assuming homogeneous raw material.

Impact of Development on Nutrition

Pinstrup-Anderson et al. (1976) apply CGCM hypotheses 2 and 3 to a study of impact of economic development on human nutrition. They estimate demands for food products and convert these into demands for proteins and calories. They then determine how increases in supplies of various food products will affect protein and calorie consumption. These results lead to suggestions as to which commodities should receive high production research priorities if improved calorie nutrition is the goal and if improved protein nutrition is the goal.

Estimation of Production Functions

Standard formulations of production functions relate quantity of a product produced to quantities of various goods and services used in production. Many investigators have estimated production functions of this type. The production function used in the previous section on Neoclassical ICM stated the quantity produced as a function of quantities of various characteristics obtained from the goods and services used in production. The only place this second type of production function has found much use is in estimation of effects of weather, soil type, nitrogen, phosphorous, potassium, or other fertilizer nutrient on crop yields. For examples, see Pesek et al. (1967), Fuller (1965), and Battese et al. (1972). Hildreth and Jarrett (1955) and Carley (1973) have estimated functions similar to this second type. In one version of their livestock production function, Hildreth and Jarrett (1955) include total digestible nutrients (TDN) in feed grains fed to livestock and TDN in protein feeds fed. In another version, they include total digestible protein fed and other digestible nutrients (ODN) fed. TDN and ODN are aggregates of several nutrients. Carley (1973) presents an equation that can be used to predict milk production (measured as net energy required for milk and butterfat production) from a dairy cow's weight and intake of calories from concentrates, from silage, from hay, and from pasture.

Also, a number of investigators have included measures of quality of inputs in their estimates of the first type of production function. Griliches (1963, 1964), Huffman (1974, 1976), and Bredahl and Peterson (1976) have included measures of educational level of the farm labor force or measures of expenditures on research by agricultural experiment stations or measures of expenditures on extension by agricultural extension services, or some combination of these measures of input quality, in estimates of agricultural production functions. For further discussion and references, see the paper by Peterson and Hayami (1976).

Value of Saving a Life

Thaler and Rosen (1975) deal with one component of value of life: the demand price for a person's own safety. They view safety and wages as characteristics of jobs. They develop a model in which workers sell labor and purchase safety, while employers purchase labor and sell safety. Equilibrium wage differentials for risky jobs are de-

termined by demand and supply functions for job safety. They measure job risk as a probability p. (In their empirical work, p measured extra deaths per thousand policy years in hazardous occupations.) W is wage. W(p) is a function relating wage rate to probability of death. Wage is also a function of personal characteristics: let c identify a vector of personal characteristics; then the function W(p,c) relates wage to risk and personal characteristics. To estimate W(p,c), Thaler and Rosen use data on individual employees. They regress employee's wage on a measure of occupational risk (p), characteristics of occupation and industry, and characteristics of employee.

In a linear equation, the coefficient of p is 0.0352. They interpret this figure as follows: ". . . the estimate 0.0352 implies that jobs with extra risks of 0.001 pay $3.52 per week more than jobs with no risk. This amounts to about $176 per year, and the slope of the regression on a yearly basis is $176,000.... Suppose 1,000 men are employed on a job entailing an extra death risk of 0.001 per year. Then, on the average, one man out of the 1,000 will die during the year. The regression indicates that each man would be willing to work for $176 per year less if the extra death probability were reduced from 0.001 to 0. Hence, they would together pay $176,000 to eliminate that death; the value of the life saved must be $176,000. Furthermore, it must also be true that those firms actually offering jobs involving 0.001 extra death probabilities must have to spend more than $176,000 to reduce the death probability to zero, because there is a clear-cut gain from risk reduction if costs were less than that amount."

Lipsey (1975) explicitly, and Kosters (1975) implicitly, criticize Thaler and Rosen's measure of risk. Their measure of risk contains two components: true occupational risk and personal-characteristics risk of individual people. The former risk is relevant to the analysis and the latter is not. Because people with certain personal characteristics may be attracted into certain kinds of jobs, the two risks may be correlated.

Whereas Thaler and Rosen deal with job safety, Broussalian (1975) analyzes safety standards in consumer products.

EFFECT OF TECHNICAL CHANGE ON PROFIT

The ICM and almost all other economic analyses of firms assume the technical conditions of production to be fixed. But many groups of people—plant breeders, animal breeders, agricultural engineers, *inter alia*—are concerned with changing the technical conditions of production. In spite of the fact that efforts of these people are at odds with the economists' assumptions, economics of the firm can provide some help in answering such questions as: "What change in technical conditions is worthwhile?" It does this by investigating the effect of change in technical conditions of production upon a firm's costs, resource use, product mix, and profit. Many technical changes represent changes in the characteristics of productive inputs.

One procedure that can be used to investigate the effect of change in characteristics of productive inputs was developed by Ladd and Gibson and applied to a swine breeding problem. That procedure is summarized here. For a more complete discussion see Gibson (1975) or Ladd (1977a).

To select superior animals for livestock improvement programs, animal breeders use selection indexes. Construction of an index requires measures of economic values of heritable traits. Economic value of a trait has been defined as "the amount by which maximum profit per animal may be expected to change for each unit of improvement in the trait." Ladd and Gibson's first step in measuring economic values of traits in swine was to formulate a linear programming statement of the profit-maximization problem of a swine farm.

Define x_j = level of jth activity, c_j = net revenue per unit of the jth activity, a_{ij} = amount of the ith fixed input used per unit of the jth activity, a_{i0} = amount of the ith fixed resource available to the firm, x_{n+i} = slack variable in the ith constraint, $C = (c_j)$ a 1 by n vector of per-unit net revenues, $X = (x_j)$ an n by 1 vector, $A_j = (a_{ij})$ an m by 1 vector, $A = (a_{i0})$ an m by 1 vector, $X_s = (x_{n+i})$ an m by 1 vector, and E_i = ith unit vector. The firm's profit maximization problem can be expressed as

Maximize $Z = CX$

subject to

$$\sum_{j=1}^{n} A_j x_j + \sum_{i=1}^{m} E_i x_{n+i} = A_0$$

all x_j, all $x_{n+i} \geq 0$

Assume B is an optimal feasible basis. Then a basic optimal feasible solution is $X_0 = B^{-1} A_0 = (x_{j0})$. The firm's maximum profit is $Z_0 = C_0 X_0$ where C_0 contains those elements of C that correspond to basic variables. The criterion element for any variable, say variable x_j, is $z_j - c_j = C_0 B^{-1} A_j - c_j \geq 0$

What happens to Z_0 if the value of some trait is changed? Changing a trait may change some of the net revenues. Changing backfat thickness of swine, for example, will change the price received for the swine. If feed is purchased, improving feed efficiency of livestock will reduce the average variable cost of production and increase net revenue per animal. Some of the c_j, therefore, are functions of the genetic traits. Changing a trait may also change some of the

a_{ij}. Changing average daily gain will make it possible to raise livestock to a specified weight more quickly and thereby reduce labor requirements and may affect space needs. The parameters of the linear program can be expressed as functions of the genetic parameters. Let g_h represent the level of the hth genetic trait. If g_h changes by one unit, the economic value of the hth trait, EV_h, is

$$EV_h = (dZ_0/dg_h)/N_h$$

where dg_h is the change in the hth trait, dZ_0 is the resulting change in maximum profit, and N_h is the number of animals from the basic optimal feasible solution that undergo genetic change (market swine in the present situation). By applying sensitivity analysis to the basic optimal feasible solution, the following computable form is obtained if the change in g_h does not change the optimal feasible basis

$$(11) \quad EV_h = [\Sigma_j x_{j0}(\partial c_j/\partial g_h) -$$
$$\Sigma_i \Sigma_j x_{j0}(z_{n+i} - c_{n+i})$$
$$(\partial a_{ij}/\partial g_h)]/N_h$$

Gibson (1975) and Ladd (1977a) applied this procedure to three different swine enterprises to compute economic values for three traits: backfat, feed efficiency, and average daily gain.

In formulating the initial linear programs, resource requirements and net revenues were determined for farms raising hogs that had typical or average values of these three traits. The values of $\partial c_j/\partial g_h$ and $\partial a_{ij}/\partial g_h$ were obtained by determining the effect of a unit change in a trait upon resource requirements and net revenues. Values of x_{j0} and $z_{n+i} - c_{n+i}$ were obtained from the basic feasible optimal solutions to the initial programs.

The linear programming formulation is not the only possible formulation. A neoclassical alternative is presented in Ladd (1977a). The neoclassical formulation for a single-product firm involves: (a) stating the firm's production function, including values of traits in the function, (b) finding the first-order and second-order conditions for the firm to maximize profit, (c) using the second-order conditions to determine the effect of change in genetic value of a trait upon profit-maximizing levels of each input and of output, and (d) aggregating the effects obtained in step (c) to determine the effect upon maximum profit of the change in genetic value.

Melton (1976) presents a production function of the kind referred to in step (a). He relates weight-gain of beef cattle to breed, energy intake, time on feed, and two genetic variables—feed efficiency and degree of maturity.

DEFINITION AND MEASUREMENT OF PRODUCT CHARACTERISTICS [6]

Some product characteristics have both standard definitions and means of measurement; e.g., length of a car, amount of protein in a pound of T-bone steak. Some have one, but not both. Some have neither.

Theory of signal detection may provide a method of measuring some characteristics. This theory was originated by electrical engineers concerned with detecting electromagnetic signals in the presence of noise and was extended by psychologists to apply to the evaluation of human perceptual judgments. Angus and Daniel (1974) applied the theory to measurement of richness of ice cream mixes. There exists no clearcut definition of richness of ice cream. Therefore, no measurement of richness exists except measures provided by human perceptual judgments. The objective of their study was to use theory of signal detection "to determine the extent to which a taste-testing panel could discern richness of ice cream products" and to relate their judgments to fat level, flavor, and overrun. If it were known that richness were a simple function of these last three variables, in a study of CGCM Hypothesis 1, a person might include these three variables and not try to include a measure of richness. If, however, richness is a complicated function of these variables, it would be preferable to use a measure of richness as one variable.

March and Herrmann's (1953, p. 66) finding that some creameries received premiums for such things as size and regularity of butter shipment or closeness to the buyer's outlets shows that, in some studies, "product characteristics" must include characteristics of dealers. This is also shown by Holdren's (1968, pp. 118-124) arguments concerning the effect of a supermarket's nonprice offer variation and width of product line upon the demand functions facing the supermarket.

As was mentioned in the previous section on Pricing Accuracy, two steps involved in pricing of live animals are prediction of carcass characteristics from live animal characteristics and prediction of salable product from carcass characteristics. A number of studies have documented the errors that occur in trying to predict carcass characteristics from visual inspection of live animals. See, for example, the reports by Engelman et al. (1953), North Central Regional Livestock Marketing Research Committee (1954), Schneidau and Armstrong (1970), Stout and Thomas (1970), and Williams and Stout (1964).

Animal scientists have investigated a number of techniques for determining characteristics of live animals and carcasses. Among them are ultrasonics, electronic meat measuring equipment, and potassium isotope ^{40}K.

Numerous workers have used longissumus muscle area and amount of fat in the lumbar-thoracic region as indexes of animal composition. Meyer et al. (1966) used ultrasonics in a study of swine, cattle, and lambs to determine the accuracy of the ultrasonic technique in the measurement of muscle and fatty tissue in the lumbar-thoracic region of live animals, to determine relationships between ultrasonic measurements at various stages of growth and measurements of the carcass, and to compare ultrasonic measurements with other objective measurements of meatiness. They concluded that ultrasonics provides an accurate method of measuring muscle and fatness of live animals and can be useful in selection of animals on the basis of longissimus muscle area and fat thickness and in studies of animal growth. This report contains an extensive bibliography and summary of previous work on ultrasonics.

An earlier evaluation of ultrasonics was presented by Stouffer et al. (1961). For a recent application, see Ramsey et al. (1972).

Measurements of the potassium isotope ^{40}K have been used as indicators of body composition. See, for example, Sim and Wellington (1976), Schmidt et al. (1974), Clark et al. (1972), and Clark, Hedrick, and Thompson (1976).

Electronics has also been used to predict cutout yields of carcasses. Electronic meat measuring equipment (EMME) relies upon the ability of lean tissues to conduct electricity better than fat tissues, and provides a measure of lean mass. Koch and Varnadore (1976) used EMME to evaluate beef carcasses and forequarters. The carcasses were cut into trimmed primal cuts, 50-50 lean-fat trim, fat trim and bone. They summarized their findings as follows (1976, p. 108): "Untrimmed weight of quarters or sides was the most imporant variable in estimating differences in trimmed cut weight. EMME number accounted for significant variation in trimmed primal cuts and reduced the standard error when used simultaneously with weight. EMME number accounted for [slightly] more variation than the combination of fat thickness, % kidney and longissimus muscle area when used simultaneously with untrimmed weight . . . . Analysis of data on 19 forequarters, which included chemical analysis of the 9-10-11th rib cut, indicated that the EMME number increased and untrimmed quarter weight decreased in relative predictive value as the item evaluated was successively primal rib, closely trimmed rib roast and fat-free lean."

EMME has also been used in evaluation of live animals. One study found that EMME number and body weight of live hogs had about the same value as body weight, loin-eye area, and backfat and as ^{40}K in predicting the weight of the four lean cuts (Domermuth et al., 1973).

Another method that has been tested is electrogrammetry. In this process, top and side view silhouettes of live animals are obtained. Measurements made from these silhouettes are used to predict characteristics of the carcass. In a study of 40 steers, Clark, Eakins, Hedrick, and Krause (1976) found that the electrogrammetry measurements accounted for 44 percent of the variance in ribeye area, and between 36 and 57 percent of the variance in wholesale cut weights of round, loin, chuck, rib, flank, and combinations of these cuts.

In one study of beef yields of carcasses, Crouse and Dikeman (1976) measured 18 traits of carcasses in the cooler. They found that adjusted fat thickness, longissimus muscle area, estimated kidney and pelvic fat, hot carcass weight, and marbling score were the most important in predicting percentage of retail products. These five variables accounted for 79 percent of the variance in percentage of retail products. For comparative purposes, note that carcass yield grade is determined from fat thickness; kidney, pelvic, and heart fat; ribeye area; and hot carcass weight.

Not everyone has given up on visual inspection. Dikeman et al. (1976) investigated the use of visual scores of cannon bone size in feeder cattle to predict carcass traits.

In 1974 the U. S. Department of Agriculture proposed a requirement that all beef carcasses that are quality graded must be yield graded. A measure commonly used in studies of yields of beef carcasses is cutability ratio. This is a percentage that equals 100 times the weight of lean, retail cuts from a beef carcass divided by the cold carcass weight. "Lean retail cuts" may be defined in various ways. One way is as the seven primal cuts: loin, rib, round, chuck, brisket, plate, and flank. Using this measure, Purcell and Nelson (1976) found that the three inependent variables, hot carcass weight, backfat thickness, and kidney and heart fat as percentage of carcass weight, explained 41 percent of the variance in cutability ratio when lean trim was not included in determining the numerator of the ratio, and explained 29 percent of the variance in the cutability ratio when lean trim was included. They also analyzed the relation between cutability ratio and yield grade. Comparison of their results from other studies lead them to conclude that the fat cover allowed on lean retail cuts influenced the relation between yield grade and cutability ratio: Increasing the allowable fat cover tends to reduce the effect of variation in yield grade upon cutability ratio. They suggested that it would be desirable to modify the yield grade standards to include the value of edible fat.

Pomeranz and Meloan (1971) survey analytical techniques and instruments used in food analysis. Their main purpose is to explain the background and principles of analytical methods. The book is written for readers who have studied general, organic, analytical, and food chemistry, and biochemistry.

A book edited by Kramer and Twigg (1973) presents many of the specific procedures used for analytical and other quality-control operations in the food industry. The book emphasizes rapid, instrumental procedures appropriate for quality control, but also covers many official methods of analysis.

Many of the books cited in later sections on Measures of Characteristics of various products contain information on methods of analysis of the specific product (or products) covered in the book.

The Economic Research Service (1965) has published a fairly complete set of data on conversion factors for agricultural commodities. For example, it presents fat solids content, nonfat solids content, total milk solids content, and amount of product per 100 pounds of whole milk for some 60 dairy products; fluid skim milk, fluid buttermilk, and fluid whey equivalent for a few products; net weight of standard units for 20 dairy products; and factors for conversion of farm weight of fluid milk and cream to retail weight. For beef it presents data on average liveweight and dressing yields of cattle and calves; yield of wholesale cuts from carcass, yields of boneless meat from wholesale cuts; relation between procurement and carcass weight for cured, corned, pickled, chipped, and dehydrated beef; factors for conversion of boneless wholesale cuts to carcass weight and to bone-in cuts; relation between procurement and product weights for edible offals; raw meat content and factors for determining carcass weight equivalent of canned meats; and factors for converting retail weight to carcass weight. For corn, it contains factors for converting bushels of corn to pounds of product and pounds of corn to pounds of product for 24 products.

SOURCES OF INFORMATION ON CHARACTERISTICS

Small Grains

Matz (1969) covers wheat, corn, oats, barley, rye, sorghum, rice, and miscellaneous cereals. This book presents data on composition, proximate analysis, and nutritional values for most of these cereals, as well as additional data on properties of some of these cereals and their products.

A book sponsored by the American Association of Cereal Chemists (AACC) and edited by Pomeranz (1971) reviews existing knowledge on the cereal chemistry of wheat. The quality of wheat depends upon the composition and properties of wheat itself and upon technology used to transform wheat into other products. The book covers wheat quality, technology, and chemistry. It contains 15 chapers and is divided into five parts: (I) Wheat, (II) Milled products of wheat, (III) Principal chemical components of wheat and flour, (IV) Dough, and (V) End products of wheat. Part I contains discussions of physical and chemical criteria of quality and of grading systems. Part II contains data on chemical composition of kernels, composition of flours of various extractions, characteristics of individual flour streams, components of quality in flour, and criteria of flour quality. One chapter in Part IV discusses the relations of chemical composition and structure of wheat components to functional properties. Part V contains information on composition of ingredients used in bakery products and in durum wheat paste products.

Inglett (1974) also presents data on wheat, flour, and bakery products. Chapter 7 contains information on kernel structure and composition. Chapter 8 contains information on amino acid compositions of wheat, flour, and flour protein fractions. Chapter 9 contains data on the carbohydrate and sugar content of wheat and its various milling products. Chapter 11 contains information on characteristics of wheat flours; amino acid, lipid, carbohydrate, mineral, and proximate composition, and vitamin content of commercial baked foods. It also contains information on composition of corn syrups, relative sweetness of various sugars, fatty acid composition of some food fats, composition and function of egg products, composition of cocoas, chocolate, and dried dairy products.

Dattaraj et al. (1975) studied the relationship between physical tests and milling properties of wheat. Physical tests included test weight, 1000-kernel weight, wheat-size, pearling, kernel density, and 1,000-kernel volume. Milling properties studied were flour yield, milling rating, and milling value. Posner et al. (1974) studied effects of three systems of blending wheats upon characteristics of blended wheat and upon characteristics of flour.

Matz (1970) contains chapters on milling, baking, feed manufacture, malting, brewing, manufacture of breakfast cereals, macaroni products, starch and oil production from cereals, and rice processing. Almost every chapter contains some information on quality characteristics of grain or grain products. The chapter on feed manufacturing contains data on nutritional composition of some 160 different feed ingredients.

Farrell et al. (1967) analyzed nine U. S. grown wheats and flour and four millfeeds made from them for protein, ash, moisture, crude fat, crude fiber, starch, bulk density, and size. Waggle et al. (1967) provides results of analysis of the same wheats and milled products for 17 amino acids, 9 vitamins, 15 minerals, and gross energy content.

Western and Graham (1961) present data on chemical and nutritional composition and energy output of oats.

Wu et al. (1972) present data on protein content of four varieties of oats and of their dry-milled fractions. Wu et al. (1973) present data on protein content of oat products produced by a wet-milling process. Wu and Stringfellow (1973) contains additional data on protein contents of oat products.

Whistler and Paschall (1967) provide a comprehensive survey of practical aspects of starch chemistry. This book is prepared primarily for people concerned with manufacture and uses of starches and starch-based products. It contains 27 chapters, grouped into four major categories: manufacture of starches (6 chapters); uses of starches in the paper, textile, and food industries (3 chapters); manufacture and uses of starch derivatives (16 chapters); analysis, identification, and microscopy of starches (3 chapters). The group of chapters on manufacture of starches covers corn, milo, wheat, rice, potato, tapioca, arrowroot, and sago starches.

A book on rice edited by Houston (1972) has two major aims as stated in its preface: "to collect and present for the first time in a single work an ordered, coherent, and informative series of reviews on rice chemistry and technology; and to provide an extensive bibliography that will permit detailed access to the primary literature." Chapter 1 on Production and Utilization of Rice contains some comparative data on composition of rice and other cereals. Chapter 2 on The Rice Caryopsis and its Composition covers gross structure of rice caryopsis and its milling fractions and has much information on composition and properties of rice caryopsis and milling fractions. Chapter 3 concerns Enzymes of Rice. Chapter 4 is titled Criteria of Rice Quality; it discusses U. S. rice standards. Chapters 5 through 9 deal with rice drying, storage, and milling. Chapters 10 through 13 concern rice flours, bran and polish, hulls, and enrichment. Chapters 14 through 18 are devoted to parboiled rice, quick-cooking rice, breakfast cereals and infant foods, canned and fermented rice foods. Chapters 19 and 20 take up rice in brewing and sake.

The first five chapters of a book edited by Cook (1962) deal with the barley plant (botany, production, and breeding), identification of different varieties, and diseases. The next three chapters take up malting: evaluation of malting barley, malting technology, and the malting process. The last three chapters cover analytical examination of barley and malt, structural chemistry of barley and malt, and enzymic content and enzymic transformation of malt.

A book edited by Inglett (1972) contains the proceedings of a symposium on seed proteins held by the American Chemical Society. The symposium reviewed synthesis, properties, and processed products of seed proteins. The three chapters in Section I are entitled Seed Proteins in Perspective, Economics and Technology of Cereal Fortification, and Seeds as a Source of Protein for Humans. Section II, entitled Protein Synthesis in Cereals, contains 4 chapters. Section III is entitled Protein Quality and Quantity. Its five chapters cover rice, wheat, corn, barley, and oats. Section IV, Seed Processing and Product Properties, covers corn, wheat, cotton seed, peanuts, and soybeans. Section V consists of 6 chapters devoted to methods of studying protein quantity and quality.

Corn and Sorghum

Wall and Ross (1970) contains information on composition of sorghum plant and sorghum grain, composition and feeding value of sorghum used for forage, yield and quality of sugar from sweet sorghum, wet-milling and dry-milling.

Chapter 7 of Doggett (1970) presents data on composition of sorghum plant and sorghum grain. Chapter 8 presents some data on composition of foods made from sorghum and on use of sorghum for livestock feed.

Rooney and Clark (1968) present an extensive review of the literature on sorghum composition. Wall and Blessin (1969) present additional information on composition and structure of sorghum.

A book edited by Inglett (1970) contains information on quality and characteristics of corn and corn products. Chapter 5 of that book briefly summarizes information on use of corn for livestock feeding. Chapter 7 contains information on structure, composition, and quality of corn kernels. Chapter 9 contains some comparative data on ordinary dent corn, high-amylose corn, and high-lysine corn. Chapter 12 presents nutrient analyses of 10 different by-products obtained from wet milling or dry milling of corn and used as animal feeds. Chapter 13 contains information on composition and properties of corn oil. Chapters 14 and 15 present information on characteristics of products of the dry-milling industry. And chapter 18 deals with the nutrient values of corn and corn products.

Two books edited by Matz (1969, 1970) contain information on corn characteristics. The first of these two books (Matz, 1969) also covers sorghum and millet, in addition to small grains.

The Whistler and Paschall (1967) book on starch chemistry contains information on corn starches and characteristics of corn relevant to production of corn starch.

Earle et al. (1946) provide data on the moisture, ash, nitrogen, oil, sugar, and starch composition of the component parts of 11 samples of corn kernels. Curtis and Earle (1946) present information on physical and chemical composition of some double-cross hybrid corn varieties.

Wolfe and Fowden (1957) present data on protein and amino acid composition of seven varieties of corn grown in East Africa.

Bressani and Conde (1961) report proximate analyses of corn and amino acid contents.

Peplinski et al. (1975) report on the effects on corn quality of harvest moisture, combine sheller damage, and drying temperature. Aspects of corn quality covered are U. S. grade, factors affecting grade, kernel hardness, germination, screenings, and proximate composition. Vojnovich et al. (1975) used the same samples of corn to evaluate effects of artifical drying and sheller damage on the wet-milling characteristics of corn.

In a study of corn quality, Jennings (1974) investigated varietal differences in: (a) quality, (b) test weight, (c) moisture, and (d) resistance to deterioration and handling. He also investigated kernel size-shape characteristics and their relation to various measures of corn quality. This study presents measures on the following corn characteristics: yield, percentage moisture, wet test weight, dried test weight, change in test weight, wet and dry displacement of 200 kernels, change in displacement, weight of 200 kernels, percentage foreign material, percentage physical damage, percentage breakage, pericarp thickness, a "quality index," and kernel size-shape properties. He also presents correlations among these characteristics.

Martin (1974) collected corn samples from fall producer-delivered corn, winter country elevator rail-shipped corn, winter terminal elevator rail-received and rail-shipped corn, and spring truck-received and barge-shipped corn. Samples were inspected for moisture, test weight, broken corn and foreign material, total damage, visible and hidden mechanical damage, germination, and breakage. He presents (pp. 91-92) means and standard deviations of these characteristics for the various samples, also (pp. 94-95 and 118-120) correlations among the characteristics in the various samples and distributions of corn characteristics by corn grades (p. 96). He also surveyed country elevators, corn processors, feed manufacturers, and corn exporters to determine what quality characteristics the different groups considered important, to obtain rankings of importance of various characteristics to the different groups, and to determine opinions on possible changes in the corn grading and pricing system.

Chapter 10 of a book edited by Inglett (1972) on seed proteins deals with two types of high lysine corn: *opaque-2* and *floury-2*. Chapter 13 of this book concerns corn proteins in relation to corn processing and nutritional value of products. Other chapters also provide information on corn proteins.

Hill (1975) contains invited papers and summaries of discussion sessions of a conference on corn quality in world trade. The four main sections of the book deal with identification of quality characteristics for food and feed users of corn, improving quality through genetic changes, measuring corn quality, and maintaining corn quality.

Hill et al. (1976) and Hill and Paulsen (1977) report on changes in quality of exported corn between origin and foreign destination. The first study dealt with changes in broken corn and foreign material in corn loaded at Toledo, Ohio, and shipped to Rotterdam. The second dealt with changes in test weight, broken corn and foreign material, moisture content, breakage and percentages of whole kernels, of particles, and of multiple stress cracks in corn shipped from Peoria, through the New Orleans port area, to Mexico.

Hall (1972) discussed effects of temperature of drying air, moisture content at harvest, and variety on changes in test weight of shelled corn during drying. Hall and Hill (1974) measure the effect of kernel damage on changes in test weight of shelled corn during drying.

In 1975 and 1976 the U. S. Department of Agriculture proposed changes in corn grades. The February 1976 proposal was (a) to remove moisture and test weight from the factors determining grade, but to continue to report moisture and test weight, and (b) to replace the broken corn and foreign material category in corn grades by three grading factors—broken corn and small kernels, screenings, and foreign material. Broken corn and small kernels would be any corn that fell through a 15/64-inch screen, but not through an 8/64-inch screen. Screenings would be fine material that fell through an 8/64-inch screen. Foreign material would be any material other than corn that remains on top of either screen.

To study the proposed change, the Iowa Development Commission (1977) collected 1,783 samples of corn. They sampled incoming and outgoing corn at country elevators, incoming and outgoing corn at Mississippi River terminals, and incoming and outgoing corn at Gulf ports. Samples were graded under the existing and the proposed standards. Foreign material, broken corn and small kernels, and screenings were chemically analyzed.

Among the findings on broken corn and foreign material were these (1977, p. 16): Under present standards, "1. About 70 percent of Iowa's corn will grade No. 1 as it comes from the farm . . . . 2. . . . essentially none of it is still U. S. No. 1 when it gets to a port at the Gulf of Mexico . . . . 4. It is apparent that the broken corn element in what is presently called BCFM is the most important among the three elements in BCFM as a cause of progressive lowering in numerical grade." It was also found that the three factors that would replace broken corn and foreign material as a grading factor do divide broken corn and foreign material into classes with different nutritional values.

Over the years, the *Transactions of the American Society of Agricultural Engineers* have contained a number of articles dealing with physical damage to corn. The American Society of Agricultural

Engineers (1968, 1972) held two symposia on measures, causes, and effects of damage to corn and soybeans.

Soybeans

A book edited by Smith and Circle (1972) reviews research and development on food uses of soybean protein products and research on utilization of these products by the food industry. The book contains 12 chapters: (1) Historical background, (2) Genetic and other biological characteristics, (3) Chemical composition of the seed, (4) Purification and properties of the proteins, (5) Organic solvent treatment of soybeans and soybean fractions, (6) Biologically active components, (7) Nutritional value of food protein products, (8) Biological processes in stored soybeans, (9) Processing soy flours, protein concentrates, and protein isolates, (10) Protein products as food ingredients, (11) Fermented soybean food products, and (12) Marketing of soybeans and their protein products.

Chapter 3 contains 21 tables of data on soybean composition. Chapter 4 presents data on protein and amino acid composition of soybeans. Chapter 7 presents data on nutritional value and nutritional composition of soybean food products and food supplements containing soybean protein. Data on soy protein concentrates, flavor components of soybeans, and functional properties of soy protein products as food ingredients are in chapters 9 and 10.

Wolf (1969, 1970) reviews different forms of soybean proteins and their functional, chemical, and physical properties.

Murken (1972) presents data on distributions of moisture, test weight, damage, splits, foreign material, and grades obtained in 199 samples of fall-farmer-delivered soybeans and 124 samples collected from soybean processors and a terminal elevator as well as data on national distributions of these characteristics for several crop years. Distributions of oil and protein content from 47 samples of fall-farmer-delivered soybeans also are presented. Murken also obtained data from 21 soybean processors on soybean characteristics they considered important, the relative importance of soybean characteristics, opinions on present and alternative grading systems, and estimates of costs of determining quality at the plant. He also investigated relationships between quality factors and market prices, grades and prices, and quality factors and actual product value.

Chapters 16 and 17 of a book on seed proteins edited by Inglett (1972) deal with soybean structure and its relationship to processing, and functional properties of edible soybean protein products.

Nichols et al. (1975) studied effects of seed varieties, lime and fertilizer applications, planting dates, soil conditions, seed treatments, herbicide ap-

plications, and cultural practices on oil and protein content of soybeans grown in North Carolina. Oil content was found to be affected by variety, application of lime, seeding date, seed treatments, and soil conditions. Protein content was found to be affected by these 5 variables and also by nitrogen and potash applications. Seeding rate, seed size, row width, and herbicide treatment were not found to affect oil and protein content.

Until recently, soybean traders have had to rely upon visual inspection and measured moisture content to estimate the value of soybeans. New infrared optical equipment that permits a quick and accurate measurement of protein and oil content of soybeans and other grains is becoming available. Updaw et al. (1976) report a system for determining oil and protein premiums and discounts for soybeans and discuss some implication for processors, handlers, and farmers if oil and protein premiums and discounts were to become widespread in soybean pricing.

Markley (1951) edited a two-volume work on soybeans. Part B (contained in volume I) is entitled Structure and Composition. It covers structure and genetic characteristics, chemical composition of seed and oil, chemical characteristics and physical properties of oil, constituents of soybeans, and nutritive factors in soybean products. Part C (divided between volumes I and II) deals with soybean processing. Part D (in volume II) concerns utilization of soybean products.

The American Society of Agricultural Engineers (1968, 1972) held two symposia on measures, causes, and effects of damage to corn and soybeans.

Livestock and Meat

Duewer (1970) shows average yields of retail cuts of beef from a 620-pound choice beef carcass and average yields of retail pork cuts from a 149-pound hog carcass.

A book by McCoy (1972) contains information on livestock and meat characteristics. It contains figures and tables showing wholesale and retail cuts of beef, veal, pork, and lamb, approximate yields of wholesale cuts (pp. 192-199), and carcass yields of retail cuts of beef and pork (pp. 229, 395-396, 398-399). Chapter 11, Grades and Grading, discusses U.S.D.A. grades for live animals and carcasses. This chapter presents information on characteristics of beef and lamb carcasses of different yield grades and equations for determining yield grades of beef and lamb carcasses.

The Journal of Animal Science is a valuable source of information on livestock carcass and meat characteristics. In 1976 that journal published 16, 5, and 3 articles that contained substantial amounts of data on beef, sheep, and hog carcass and meat traits, respectively. The three articles that present data on hog carcass composition are by Bereskin and Davey

(1976), Davey (1976), and Domermuth et al. (1976). The last one also compared EMME with ^{40}K as means of estimating lean body composition of live pigs. In addition to data on carcass traits, the article by Davey (1976) contained taste panel evaluations of cooked pork.

Articles by Kemp et al. (1976), Boylan et al. (1976), Thomas et al. (1976), Wiggins et al. (1976), and Campion, Field, Riley, and Smith (1976) present data on carcass traits of sheep. The articles by Kemp et al. and by Thomas et al. also present data on yields of wholesale cuts. The articles by Kemp et al. and by Campion et al. also present data on cooking losses and palatability.

McAllister et al. (1976) present data on 19 beef carcass traits; 9 wholesale cut weights; 20 lean, fat, and bone components of left side of carcasses; and 10 retail-cut weights and percentages. Crouse and Dikeman (1976) contains data on 27 different beef carcass traits and retail yields. Dinius et al. (1976) present data on 9 beef carcass characteristics and 6 measures of organoleptic evaluations of beef. Koch et al. (1976) present data on 25 different beef carcass traits and 4 measures of taste panel evaluation. Carroll et al. (1976) present information on maturity, marbling, and 8 sensory evaluations of beef cuts. In addition to these five articles, 1976 issues of *Journal of Animal Science* contained 11 other articles that presented substantial amounts of data on beef traits: Fields et al. (1976); Clark, Hedrick, and Thompson (1976); Clark, Eakins, Hedrick, and Krause (1976); Hallford et al. (1976); Olentine et al. (1976); Dean et al. (1976); Kauffman et al. (1976); Koch and Varnadore (1976); Gill et al. (1976); Campion, Crouse, and Dikeman (1976); and Potter et al. (1976).

Some articles in the *Journal of Animal Science* present averages in the form of "least squares means" and "adjusted least squares means." These terms, which are unfamiliar to economists, are explained in an appendix in this bulletin.

Topel (1968) contains a substantial amount of information by various authors on characteristics of hogs, carcasses, and pork. Part Three of the book is entitled Nutritional Influences on High-quality Production and presents data on effects of diet on live hog performance characteristics, on carcass characteristics, and on characteristics of pork cuts. Part Five is entitled Importance of Selection and Breeding Characteristics on Muscle Quality. This part presents information on effect of transport, season, and chilled carcass weight on muscle color score and on pH, and presents information on phenotypic variation and heritability of muscle color and pH in chapter 11. Part Five presents data on intra- and inter-breed variation in quality and quantity factors in chapter 13, and presents information on live-hog performance characteristics and carcass characteristics from swine-testing stations in chapters 14 and 15. Chapter 18 relates influence of controlled environmental temperature and humidity on live-hog performance characteristics and on carcass characteristics. Incidentally, pages 22-24 of this book present a discouraging report on the efforts of a restaurant chain to develop methods of predicting and controlling eating quality of fresh pork cuts and on the consequent decision of the chain to reduce the frequency of listing fresh pork cuts on its menus. The chain had, however, increased the frequency of listing processed pork products on its menus.

Lawrie (1970, pp. 141-166) presents some data on body and carcass composition of livestock. This same book also presents data on nutritional composition of milk (pp. 214-217), poultry meat and eggs (pp. 226-239), and quantity and quality of protein from different plant and animal foods (pp. 246-253).

Hedrick (1968) summarizes most of the research reported since 1859 on growth and development of the beef animal, factors influencing physical and chemical composition of the beef animal, and methods used to quantitatively evaluate growth and development of the beef animal and composition of the beef carcass.

Kramlich et al. (1973) deal with processed meats. Their emphasis is on sausages, smoked meats, and canned meats, but they also deal with curing and meat cookery. Chapter 2 concerns composition and nutritive value of raw materials and processed meats. It contains eight tables of data on nutritional values taken from Watt and Merrill (1963). These eight tables cover calorie, water, protein, fat, ash, mineral, and vitamin content of various grades and cuts of meat; calorie, water, protein, fat, carbohydrate, ash, mineral, and vitamin content of some sausages and canned meat items; calorie, water, protein, fat, carbohydrate, ash, mineral, and vitamin content of some canned baby foods; and calorie, water, protein, fat, carbohydrate, ash, mineral, and vitamin content of some cured, canned, or processed products. It also contains a table, supplied by Swift and Company, of nutritional analysis of 13 different meat products. Chapter 8 concerns least-cost formulation and pre-blending of sausage. It contains four tables of data on characteristics of sausage ingredients. Chapter 13 presents procedures for analyzing raw materials, emulsions, and finished products.

Members of the staff of the American Meat Institute Foundation (1960) summarized knowledge on meat and meat products. Part one, The Basic Science of Meat, covers meat structure, chemistry, microbiology, and chemical and physical methods of analysis. Part two, The Science of Meat Processing, covers quality factors, preservation, curing, packaging, sausage, and by-products.

Milk and Dairy Products

Henderson (1971) presents information on composition and physical and chemical properties of milk, milk flavors, and nutritional properties of milk

and dairy products. These topics are also covered by Eckles et al. (1951). Webb and Whittier (1970) contains data on composition of by-products of milk and on nutritional characteristics of milk components. Perhaps no other book contains as much data on chemical composition and characteristics of milk as does the book edited by Webb et al. (1974). It treats composition of milk and milk products, proteins, lipids, lactose, vitamins, and physical properties of milk, as well as other topics. Lawrie (1970, pp. 214-217) contains data on nutritional composition of milk. Arbuckle (1972) discusses ingredients, characteristics, and processing of ice cream. An Agricultural Marketing Service (1974) publication presents federal and state standards for composition of dairy products. The *Journal of Dairy Science* publishes articles on characteristics of milk and dairy products.

Poultry Products

A book edited by Stadelman and Cotterill (1973) provides data on eggs and egg products. Chapter 3 deals with quality identification. Chapter 7 presents data on nutritional values and nutritional composition of eggs, and chapter 9 presents data on composition and nutritional value of egg products. Chapter 16 deals with eggs' functional properties that make them useful ingredients in food products.

Mountney (1976) provides information about characteristics and composition of poultry meats and their products and of eggs. This book contains chapters devoted to quality identification, quality maintenance, quality measurement, yields and characteristics of poultry meat, characteristics of eggs, and chapters on specific processed poultry products. The chapters on quality identification deal with U. S. grades and standards. The chapter on yields and characteristics of poultry meat contains data on dressing percentages, yields of various edible parts, and yields of cooked edible portions for various kinds of poultry.

Lawrie (1970, pp. 226-239) presents information on nutritional composition of poultry meat and eggs.

The journal, *Poultry Science,* published by the Poultry Science Association, Inc., contains articles that present information on characteristics and quality of poultry and poultry products.

Livestock and Poultry Nutrition

The most comprehensive source of data on composition and nutritional value of livestock and poultry feeds is a book published by the National Academy of Sciences—National Research Council (1971). This 772-page book collects analytical data published in 12 different publications, and also presents data published before September 1969 in scientific journals. It also contains previously un-

published data. This book presents data on 6,152 feeds, both on an "as fed" basis and on a "dry" basis. It contains data on digestible and metabolizable energy of feeds for cattle, horses, sheep, and swine; data on metabolizable energy of feeds fed to poultry; and net energy of some cattle feeds.

Morrison (1956) lists analyses for a number of feedstuffs. One table presents average composition, digestible nutrients, mineral and fertilizing constituents, and digestion coefficients for some 300 dry roughages, 275 green roughages and roots, 100 silages, and 420 concentrates. Another table lists net energy values and feed evaluation factors for some 100 dry roughages, 110 green roughages and roots, 50 silages, and 180 concentrates. Another table lists contents of 12 minerals in some 70 dry roughages, 70 green roughages and roots, 15 silages, and 115 concentrates. A fourth table presents vitamin contents of some 60 dry roughages, 40 green roughages and roots, 15 silages, and 140 concentrates. A fifth table lists amino acid contents of 75 feeds. Morrison also presents information on nutrient requirements and tables of feeding standards.

A two-volume work edited by Cuthbertson (1969) and containing some 1400 pages in 35 chapters covers such topics as methods of analysis of feedstuffs; physiology of digestion, absorption, and metabolism; mineral nutrition and metabolism; nutrition and reproduction; nutrition of various species of livestock; and economics of animal nutrition.

The most comprehensive source of information on poultry nutrition is a 1500-page book by Ewing (1963).

In addition to the four lengthy publications cited in the preceding four paragraphs, a number of shorter texts are available that deal with nutrient requirements of livestock, nutrient composition of feedstuffs, and ration formulation. Among them are books by Jurgens (1972), Cullison (1975), Schaible (1970), McDonald et al. (1969), McCullough (1973), Hoglund et al. (1959), Morgan and Lewis (1962), and Titus and Fritz (1971). Matz (1970) contains a chapter on feed manufacturing that presents data on nutritional composition of some 160 different feed ingredients.

The most authoritative and widely-used data on nutrient requirements are those published by the National Academy of Sciences—National Research Council (NAS-NRC) in their series on nutrient requirements of domestic animals. Arranged according to series number, these are:

1. Poultry (NAS-NRC, 1966c),
2. Swine (NAS-NRC, 1968b),
3. Dairy cattle (NAS-NRC, 1966a),
4. Beef cattle (NAS-NRC, 1970),
5. Sheep (NAS-NRC, 1975),
6. Horses (NAS-NRC, 1966b),
7. Mink and foxes (NAS-NRC, 1968a),
8. Dogs (NAS-NRC, 1974a),

9. Rabbits (NAS-NRC, 1966d),
10. Laboratory animals (NAS-NRC, 1962),
11. Trout, salmon, and catfish (NAS-NRC, 1973).

The content of report no. 4, which deals with beef cattle, is typical of contents of each of these reports. This report covers: feed consumption and rates of gain, nutrient requirements and symptoms of deficiency, feed additives, water, composition of feeds, and formulating rations. It discusses the net energy, metabolizable energy, and total digestible nutrients systems for expressing energy requirements.

Human Nutrition

Watt and Merrill (1963) present data on composition of nearly 2,500 food items. The report includes data for energy, proximate composition, five vitamins, six minerals, water, ash, fiber, fatty acids, and cholesterol. The nutritive values of foods presented are based on extensive review of the literature and were (at time of publication) the values considered most representative for each food item described. The Watt and Merrill report is the principal source of data used by Adams (1975) in her report on nutritive values of foods. The Adams report presents some new and revised data, but does not cover all the food items included in Watt and Merrill. The Agricultural Research Service (1971) has prepared a brief report on nutritive values for household measures of commonly used foods. This report also contains an abridged table of recommended daily dietary allowances.

A comprehensive set of recommended dietary allowances is published by the National Academy of Sciences—National Research Council (1974b). This report discusses functions of known nutrients in maintaining a level of "good health" in healthy people. Invalids and others with chronic diseases would have slightly different requirements. It describes foods that contain the different nutrients and how the required intake of each nutrient changes with various age-sex categories. It speculates on the role played by nutrients so far not totally studied. It gives daily nutritional recommendations for various age-sex categories.

Food processing is an essential part of the food industry. In most instances, food processing reduces the nutritional value of foods. A book edited by Harris and Karmas (1975) is concerned with the nutritional effects of the processing of foods. Its main purpose is (1975, p. ix) "to evaluate the known effects of processing upon the nutritional values of foods, and to indicate how certain processing procedures may be altered to minimize losses in nutritional value." This book is divided into five sections: I, Introduction; II, Nutrients in raw foods; III, Effects of commercial processing and storage on nutrients; IV, Effects of preparation and service of food on nutrients; and V, Nutrification and nutrient metabolism. The five chapters in section II deal with genetic manipulation to improve nutritional quality of vegetables; effects of processing on nutritional quality of oilseed meals; and effects of agricultural practices, harvesting, handling, and refining operations on the composition of foods. The seven chapters in section III deal with the effects on nutrients of heat processing, freeze-preservation, moisture removal, fermentation, additives, ionizing radiation, and packaging. The two chapters in section IV cover effects upon nutrient content of food preparation practices in food service establishments and in the home. Section V contains two chapters that deal with addition of amino acids, vitamins, and minerals to foods and with nutrient metabolism.

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APPENDIX: LEAST SQUARES MEANS

The first column of table A-1 presents least squares means from Bereskin and Davey (1976). The most detailed classifications in this table are on lines 5 through 12. Each least squares mean on these lines is a within-group (or subclass) mean. Line 5, for example, shows that the mean backfat thickness for Duroc high-fat barrows is 8.06 cm. Lines 1 through 4 refer to less detailed classifications, or to pooled data. Each least squares mean on these lines is a mean of within-group means. For example, the 8.02 on line 1 is the mean of 8.06 and 7.98 from lines 5 and 6. The least squares mean on line 13 is the mean of the entries on lines 1 through 4; alternatively, it is the mean of the entries on lines 5 through 12. Thus, a least squares mean is a within-group mean, or it is a pooled mean obtained by pooling within-group means and assuming the same number of observations on each group.

Some of the swine in the Bereskin and Davey study were fed a diet containing 14 percent protein, and some were fed a diet containing 20 percent protein. The adjusted least squares means in column 2 (which are artificial data) present estimates of what the means would have been if all animals had received a diet containing 20 percent protein. Each adjusted least squares mean on lines 5 through 12 is obtained from a regression equation containing only within-group (or subclass) data. By using data on Duroc high-fat barrows to estimate the regression of backfat on protein and using the regression coefficient to compute backfat if all Duroc high-fat barrows were fed a 20-percent protein diet, it is estimated that the resulting mean backfat thickness would be 8.10 cm. (line 5). The adjusted least

squares means on lines 1 through 4 and line 13 are obtained from the adjusted within-group means in the same way that least squares means on lines 1 through 4 and line 13 are obtained from within-group means; as simple averages.

The least squares mean for a group estimates the mean for the group if all subgroups within the group had the same number of observations and if each subgroup mean were the same for the adjusted number of observations as it was for the actual number of observations.

Table A-1. Least Squares Means and Least Squares Means Adjusted to a 20-Percent Protein Diet

		Average Backfat (cm.)	
		Least Squares Means	Adjusted Least Squares Means
Line	**Group or Statistic**		
	Breed-line		
1	Duroc high-fat (DH)	8.02	8.05
2	Duroc low-fat (DL)	3.35	3.36
3	Yorkshire high-fat (YH)	6.65	6.63
4	Yorkshire low-fat (YL)	2.90	2.93
	Breed-line-sex		
5	DH barrows	8.06	8.10
6	DH gilts	7.98	8.00
7	DL barrows	3.66	3.68
8	DL gilts	3.04	3.04
9	YH barrows	6.74	6.76
10	YH gilts	6.56	6.50
11	YL barrows	3.22	3.20
12	YL gilts	2.58	2.66
13	Least square mean (m)	5.23	5.24

Source: Column 1 from R. Bereskin and R. J. Davey. Breed. line. sex. and diet effects and interactions in swine carcass traits. J. Anim. Sci. 42:43-51. 1976. Column 2 is artificial data.

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