FACTOR SUBSTITUTION IN U.S. MANUFACTURING: DOES PLANT SIZE MATTER?

By

Sang V. Nguyen and Mary L. Streitwieser
Center for Economic Studies
U. S. Bureau of the Census
Washington D. C., 20233

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DC 20233-6101, (301-457-1882) or INTERNET address snguyen@info.census.gov.

ABSTRACT

We use micro data for 10,412 U.S. manufacturing plants to estimate the degrees of factor substitution by industry and by plant size. We find that (1) capital, labor, energy and materials are substitutes in production, and (2) the degrees of substitution among inputs are quite similar across plant sizes in a majority of industries. Two important implications of these findings are that (1) small plants are typically as flexible as large plants in factor substitution; consequently, economic policies such energy conservation policies that result in rising energy prices would not cause negative effects on either large or small U.S. manufacturing plants; and (2) since energy and capital are found to be substitutes, the 1973 energy crisis is unlikely to be a significant factor contributing to the post 1973 productivity slowdown.

Keywords: Factor Substituting; Plant Size; Micro Data; Morishima Elasticity of Substitution.

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“*Factor substitution is a micro economic phenomenon, and is best examined by looking at microeconomic data.”*
John Solow (**American Economic Review**, 1987, p. 612)

*“Great advances have been made in theory and in econometric techniques, but these will be wasted unless they are applied to the right data***.”**
Zvi Griliches (**American Economic Review,** 1994, p. 2)

1. Introduction

The goal of this study is two-fold. First, we use micro data to assess the possibilities of differences in factor substitution between small and large production plants. Second, using a better measure of factor substitution, we re-examine the technical relationships among primary factors of production in the U.S. manufacturing sector. To accomplish these objectives, we develop and estimate a translog production function for the U.S. manufacturing sector as a whole as well as separate production functions for various plant size classes within individual (four digit) industries. We then use the model parameter estimates to compute four different types of input elasticities for the entire U.S. manufacturing sector as well as for various sizes of plants. Finally, we use the estimated elasticities to make inferences regarding the substitution/ complementarity relationships among the production inputs as well as whether or not these relationships differ between small and large establishments. Our empirical work is based on data for 10,412 U.S. manufacturing plants taken from the newly available 1991 Manufacturing Energy Consumption Survey (MECS) and the 1991 Annual Survey of Manufactures (ASM).[1]

We undertake this research for three specific reasons. First, changes in an input price have significant effects not only on the demand for that input, say energy (E), but also on the utilization rates of other primary factors of production such as capital (K), labor (L) and materials (M). The directions of these effects, however, depend upon the technical relationships among the various factors. Thus, evidence on these relationships undoubtedly has important economic policy implications.

To illustrate: if energy and capital are complements, rising energy prices would lead to a reduction in the demand for capital goods and, thereby, a slowdown in labor productivity growth (see Berndt, 1982). In this case, policies resulting in higher energy prices (e.g., energy conservation) would be counterproductive. In contrast, if energy and capital are substitutes, such policies would have the desired effect. While there has been a general consensus among researchers on the substitutability between capital and labor, capital and materials, and labor and materials, as we discuss below, empirical evidence on the relationships between energy-capital and energy-labor have been subject to great controversy. Further research on this topic is, therefore, imperative.

Second, in recent years, there has been a growing body of evidence that small businesses play an increasingly significant role in the U. S. economy, and that a large portion of economic growth and change come from them (e.g., see Brock and Evans, 1986). In particular, the 1987 Economic Report of the President to the Congress reviewed the literature of small businesses and concluded that small firms are not necessarily less efficient than large firms. To explain the efficiency of small firms, the Report cited the following factors, among other things:

> *"Many small firms act as market demand "shock absorbers." By employing flexible production technologies (emphasizing the use of labor and less capitalized capital goods), small firms have greater flexibility than large firms in adjusting their relative production levels and are thus better able to accommodate random, short-term fluctuations in demand..." (pp. 108-109)*

An important question, therefore, is whether small firms are more flexible than large firms in utilizing factors of production (in particular labor and capital). This is equivalent to asking whether the degrees of substitution among production inputs in small firms are greater than in large firms. Thus, it is important to assess separately the substitution relationships among factor inputs in the production of small and large establishments. Results of such an analysis would provide useful guidance for economic policy makers. For example, if energy and capital are substitutes in the production of large establishments, but they are complements in small production plants, then increases in energy prices would increase capital formation in large establishment. At the same time, such energy price increases would reduce small establishments' demand for capital and, hence, their labor productivity. However, if the two inputs in question are substitutes, then rising energy prices would increase capital formation and, thereby, increase productivity in all establishments regardless of size.

Yet, to our knowledge, there is only one published study that examines factor substitution in production by size classes. Nguyen and Reznek (1993) used plant level data for the years 1977 and 1982 to study factor substitution by size plant classes for five U.S. manufacturing four digit industries[2]. They found that (1) capital, labor and materials (including energy) are substitutable and (2) the degrees of substitution among the three inputs are similar across establishments of all size classes. They concluded that small establishments are as flexible as large establishments in terms of substituting one input for another in response to increases in input prices.

While Nguyen and Reznek's findings provide valuable insight into the issue of factor substitution in production across plant sizes, their work is based on only five four digit industries and may not represent the entire U.S. manufacturing sector. Moreover, their data did not permit them to treat energy as a separate input in their production function. Thus, Nguyen and Reznek's results do not provide any evidence on the technical relationship between energy and capital, and energy and labor. In this study, we extend Nguyen and Reznek's work in two dimensions: we use a micro data set representing the entire U.S. manufacturing sector and we treat energy as a separate input in the production function. We believe that our extended data and augmented model allow us to draw conclusions with more confidence regarding the comparative flexibility of small and large U.S. manufacturing plants in utilizing inputs in production.

Finally, since Hudson and Jorgenson's (1973) and Berndt and Wood's (1975) findings of energy-capital complementarity and Griffin and Gregory's (1976) evidence of energy-capital substitution, researchers have devoted considerable efforts to reconciling these conflicting results on different fronts. Among other things, these include efforts to improve: (1) model specifications[3], (2) functional forms[4], (3) input measurement[5], and (4) data used.[6] But, after more than two decades, economists have not yet come to an agreement as to whether energy and capital are complementary or substitutable.

We note that while previous studies on factor substitution differ in many respects, they have two things in common. First, until recently, virtually all studies of factor substitution used data aggregated at various levels because micro data were not available. Second, most studies used the Allen partial elasticity of substitution (AES) and cross-price elasticity (CPE) of factor demand as standard measures of factor substitution (e.g., see Berndt and Wood, 1975; Ozatalay, Grubaugh, and Long, 1979; and Hisnanick and Kyer, 1995).

Solow (1987) has argued that previous elasticity of substitution estimates based on aggregate data are misleading because they are subject to intractable aggregation biases. He pointed out that aggregate manufacturing outputs consist of many products that have different energy intensities. Thus, when energy prices vary, changes in the composition of aggregate output will take place concurrently with factor substitution that occurs within the production of each product. As a result, it is not possible for researchers to sort out these effects with aggregate data.[7, 8]

More fundamentally, other economists have contended that the AES does not accurately measure factor substitution. Blackorby and Russell (1989) have shown that the Morishima elasticity of substitution (MES),[9] rather than the AES, is an exact measure of factor substitution, in terms of adjustment along an isoquant.

. In spite of its theoretical superiority, the MES has been used rarely for measuring factor substitution. To our knowledge, there have been only a few published studies that used the MES in their empirical work. Ball and Chambers (1982) applied both the AES and MES to measure factor substitution in the U.S. meat products industry. Sickles and Streitwieser (1992) used the MES in their analysis of the technical inefficiency of the U.S. interstate natural gas pipeline industry. Finally, Nguyen and Reznek (1993) also used both the AES and MES to measure factor substitution in five U.S. manufacturing four digit industries. While these studies are useful, their findings are limited to a few selected industries and may not represent a broad sector of the U.S. economy.

In this paper, we estimate the MES, a theoretically correct measure of factor of substitution, with data on the appropriate production unit: the plant.[10] For comparison, we also estimate and report the corresponding AES and CPE of demand. With the micro data and correct measure of elasticity of substitution, we are confident that our empirical results will provide much insight into the issue of factor substitution/complementarity in U.S. manufacturing as well as into the comparative flexibility of small and large production plants in utilizing factor inputs.

Two principal findings emerge with striking clarity from our study. First, based on MES estimates, we find that capital, labor, energy and materials are all substitutes in production;

and capital and energy are strongly so. Second, except for some industries, the degrees of substitution among the inputs are quite similar across all size classes. Two important implications of these findings are: First, in U.S. manufacturing, small plants are generally as flexible as large plants in input substitution; consequently, economic policies such as energy conservation policies resulting in rising energy prices would not cause disproportional negative effects on any particular size class within U.S. manufacturing. Second, since energy and capital are not complements, the 1973 energy crisis is unlikely to be a significant, direct factor contributing to the post-1973 productivity slowdown.

The remainder of the article is organized as follows. Section 2 discusses the empirical model and elasticity measurement. Data and estimation methods are described in Section 3. Section 4 reports and discusses the results. Section 5 contains concluding remarks and a plan for future research.

2. Measuring Factor Substitution

2.1. A Production Function Model

Elasticities of substitution among factors of production can be estimated using certain parameter estimates of either a production function or its dual cost function. For empirical implementation, we assume that there exist a production function that relates output and factors of production such that

$$Q = F(X, Z) \tag{1}$$

where Q denotes output, X is a vector of inputs, and Z is a vector of other relevant explanatory variables.[11]

If Q is homogeneous of degree λ, then

$$F(X, Z)r^{\lambda} = F(rX, Z), \tag{2}$$

where λ is a constant and r is any positive real number. Assuming cost minimization and using the generalized Euler's theorem, we can derive the following cost share equation system:

$$\begin{aligned} S_i &= f_i / \lambda F, \\ &= (1/\lambda)(\partial lnQ / \partial lnX_i), \end{aligned} \tag{3}$$

where $f_i = \partial F/\partial X_i$.

For estimation we need a specific functional form for F. Because we are interested in factor substitution in production, it is most appropriate to use a functional form that does not impose unnecessary restrictions on the relationships among the factor inputs. Most previous studies have used the translog form to examine the technical relationships among factors of production. For comparison, we specify the following KLEM translog production function[12]

$$\begin{aligned} lnQ = \alpha_o + \sum_{i=1}^{4} \alpha_i lnX_i + \frac{1}{2}\sum_{i=1}^{4} \sum_{i=1}^{4} \beta_{ij} lnX_i lnX_j + \\ \sum_{k=1}^{140} \alpha_k IND + \sum_{r=1}^{9} \alpha_r REG, \end{aligned} \tag{4}$$

where ln is the natural logarithm, Q is output, and X_i are the factor inputs K, L, E, and M. Industry and geographic region are represented by the class dummy variables IND and REG, respectively. Industry dummies are included in the model to account for industry specific effects, including industry specific energy price variations. Geographic region is included to accommodate region specific effects, particularly regional differences in energy prices.

Differentiating equation (4) with respect to each factor input and assuming competitive input markets and cost minimization, we derive the logarithmic marginal productivity conditions, or cost share equations, of the following form:

$$S_i = \frac{1}{\lambda}(\alpha_i + \sum_{j=1}^{4} \beta_{ij} lnX_j), \tag{5}$$

where λ is the degree of homogeneity, or returns to scale, of the production function F.

2.2. Elasticities of Substitution

Conventionally, the AES and the CPE of factor demand are used to measure the substitution relationships among inputs in production. The AES between input X_i and X_j is defined as[13]

$$\sigma_{ij} = \frac{|\bar{F}_{ij}|}{|\bar{F}|} \frac{\sum_{i=1}^{4} f_i X_i}{X_i X_j} \qquad for\ all\ i,\ j, \tag{6}$$

where X_i is the i^{th} input and f_i is the partial derivative of the production function F, with respect to X_i. $|\bar{F}|$ is the determinant of the bordered Hessian matrix $\bar{F}$ and $|\bar{F}_{ij}|$ is the cofactor associated with element f_{ij} in $\bar{F}$.[14]

Allen (1938) has shown that the price elasticities of factor demand are related to the AES as follows

$$\eta_{ij} = \frac{\partial X_i}{\partial w_j} \bullet \frac{w_j}{X_i} = S_j \sigma_{ij}, \qquad for\ all\ i,\ j, \tag{7}$$

where η_{ii} and η_{ij} are the own and cross-price elasticities of factor demand, and w_i and S_i are the i^{th} factor's input price and cost share.

From (7) it is clear that the AES is simply a disguised CPE obtained by dividing the CPE by a cost share. Therefore, it does not have a clear interpretation. In spite of its shortcomings, as mentioned earlier, the AES has been used as a standard statistic reported in empirical studies of factor substitution in production. Recently, researchers have begun to highlight the weaknesses of the AES. In particular, Blackorby and Russell (1989) show that the AES is uninformative: it does not measure the ease of substitution and provides no new information about factor shares. More important, they show that an alternative, the MES, is an appropriate measure of factor substitution (or complementarity) because it is an exact measure of the curvature of the isoquant (or the ease of substitution).

Blackorby and Russell (1989) show that the MES can be defined as

$$\sigma_{ij}^{m} = \eta_{ij} - \eta_{jj}, \qquad \textit{for all } i,\ j. \tag{8}$$

Substituting (7) into (8), we can define the MES in terms of the AES, as

$$\sigma_{ij}^{m} = S_j(\sigma_{ij} - \sigma_{jj}), \qquad \textit{for all } i,\ j. \tag{9}$$

Note that, unlike the AES, which is symmetric, the MES is not necessarily symmetric, in absolute value, or in sign. Consequently, in the case of more than two inputs, the classification of one input as a complement or substitute for another input will depend on which input price changes. From (9) it can be seen that two inputs which are AES substitutes are also Morishima substitutes because σ_{jj} is always negative. However, the converse does not hold. A pair of Allen complements may be substitutes by the Morishima measure. In fact, if $|\eta_{jj}| > |\eta_{ij}|$, then input i and input j are Morishima substitutes regardless of the sign of η_{ij}.

We emphasize that while both the AES and CPE are one-price-one-factor elasticities, the MES (σ^{m}_{ij}) is a one-price-two-factor elasticity, which measures the percentage change in the ratio of input *j* to input *i* when the price of input *i* changes one percent, assuming that prices of other inputs are held constant. Chambers (1988) shows that the MES can be modified to measure the technical substitution between two inputs in response to changes in their relative prices. He derives the following shadow elasticity of substitution (SES):

$$\sigma_{ij}^{s} = \frac{S_i}{S_i+S_j}\sigma_{ij}^{m} + \frac{S_j}{S_i+S_j}\sigma_{ij}^{m} \qquad for\ all\ i,\ j. \tag{10}$$

where S_i and S_j are cost shares of input *i* and input *j*. Thus, the two-price-two-factor σ^s is a weighted average of two MESs where the weights are given by the relative cost shares of the two inputs under consideration. An advantage of this elasticity over the un-weighted MES, σ^m, is that it measures the responsiveness of input ratios to changes in their relative prices. For comparison, in this paper we estimate and report all four types of elasticities.

2.2. Small versus Large Enterprises

During the last two decades, there has been a growing body of empirical studies focusing on small and large enterprises and/or production units.[15] These studies cover a wide range of topics and the empirical evidence is mixed. The rates of entry, growth, and exit appear to be inversely related to size for U.S. plants and firms (relative to larger plants and firms), as documented by Pakes and Erikson (1998), Dunne, Roberts, and Samuelson (1988, 1989), and Bates and Nucci (1990).   Economic performance by small firms also appears to be lower than that of larger firms, regardless of whether performance is measured by productivity, efficiency (Caves and Barton, 1990), or profitability (Bradburd and Ross, 1989). Dunne (1994) found small manufacturing plants use less advanced technology than large plants. These works indicate that small establishments and firms in the U.S., particularly in manufacturing, perform at a lower level than larger establishments and firms.

On the other hand, Acs (1996) argues the trend toward increasing firm size has “... either decelerated, ceased, or reversed itself.”[16]   In addition, Acs, Audretsch, and Carlsson (1991) found that the application of certain advanced technologies, such as numerically controlled machines is associated with the increased presence of small firms. Hansen (1992) found some evidence that small firms are just as innovative in terms of new products as larger firms, and perhaps more so. Cohen and Klepper (1992), however, found that the relationship between firm size and innovation varies by industry.

Despite the extensive literature related to small scale economic activity, to our knowledge, there is no comprehensive theory to explain whether or not small production units are different from large ones in terms of factor substitution; nor is there a body of empirical work on this issue. There are, however, certain hypotheses regarding the performance of certain firm sizes which suggest there might be differences in production technology and therefore factor substitution possibilities. For example, Piore and Sabel (1984) argue that flexible production promote the relative viability of small firms. Aiginger and Tichy (1991) form several hypotheses regarding the superior performance of small firms relative to large firms. One of these hypotheses appears to be related to differences in factor substitution among firm sizes: smaller firms are managed by owners whose goal is profit maximization, while large firms are managed by managers who are interested in maximizing their own utility function. If this hypothesis is correct, then small production units' profit-maximizing owners will efficiently and promptly adjust their input mix in response to a price shock, while large firms may be slower to respond. Empirically, this means that elasticities of substitution in small establishments are large than those in larger production units.

Another aspect of firm organization which may impact substitution flexibility is the presence of labor unions. Katz, Kochan and Keefe (1987) argue that labor organization has a negative effect on industrial efficiency. In this regard, most small manufacturing establishments are not unionized and, hence, they are more flexible in terms of hiring (or firing) workers. This is consistent with higher substitution elasticities in small establishment between labor and other factor inputs.

On the other hand, Clark (1980) and Freeman and Medoff (1984) argue that because of unions, large firms have advantages over small establishments (or single-unit firms). Specifically, labor unions in large firms can increase efficiency by resolving grievances and reducing employee turnover costs. It is also argued that with optimal utilization of part time employees, large firms can be very flexible in employing labor in response to stochastic elements (Caves and Barton, 1990). Thus, for example, large firms can be flexible in substituting labor for other factor.

The above discussion suggests that the issue of factor substitution in small and large production units cannot be settled on the theoretical ground. Empirically, because technologies and optimal plant size differ across industries, we would expect some differences in factor substitutions between small and large establishments in some industries, but no differences in other industries.

3. Data and Estimation Procedures

3.1. Data

We utilize a recently available micro database, integrating the 1991 Manufacturing Energy Consumption Survey (MECS) with the 1991 Annual Survey of Manufacturers (ASM), both conducted by the U.S. Bureau of the Census. The 1991 MECS is a unique plant level data set which provides an excellent opportunity for examining energy-capital substitution in U.S. manufacturing. Our cross-section data set, containing a large number of observations, allows us avoid the problems and biases associated with small samples used in most previous studies. While cross-section data are subject to some limitations, they have certain advantages for this study. First, cross-section data reflect technology and market conditions at a single time period; thus, the data help avoid the problem of separating the effects of factor substitution from those of technological change and changes in market conditions on production. Second, cross section data also eliminate other effects such as dynamic adjustments due to changes in relative prices and external shocks that we cannot control with time-series data.

The 1991 MECS surveyed over 14,000 manufacturing plants with 20 or more employees, collecting information on quantities and expenditures of energy consumed in production for 37 energy sources. The data on energy are exactly what we need for estimating production function that includes energy as a factor of production. Quantity of fuel is reported in a variety of measures, such as Btu, tons, cubic feet, gallons, or barrels, depending on the fuel type. We convert the various physical units to Btu content in order to sum over all types of fuels.

While the MECS provides excellent data for energy analysis, it does not collect information on outputs and non-energy inputs, which are required for estimating a production function. Measures of output, capital, labor, materials, and size are obtained from the 1991 Annual Survey of Manufacturers. The nature of the data collected in the ASM places some constraints on the measurement of production inputs and output. Output is measured by the value of inventory adjusted shipments. Capital inputs are represented by book value of equipment and structures;[17] labor is defined as total production worker equivalent man-hours, and materials are measured by the value of materials and parts used in production. Plant size is measured by number of employees.[18]

Cost shares of inputs are calculated by dividing expenses for each input by total expenses. We assume zero excess profits, thus total expenditures are equal to the value of output. Expenses for labor include total salaries, wages, and other labor expenses. Energy expenditures are the sum of expenditures across all types of energy consumed in production. Material expenditures are the cost of materials, parts, and contract work. Lastly, capital expenses, and therefore the capital cost share, is the residual remaining after netting out the expenses for labor, energy, and materials from total expenditures. After matching the two data sets and omitting plants with missing or imputed data values, we have 10,412 plant observations in our final data set.[19]

Sample means for the data used in estimation are reported in Table 1. The first six columns show the variable means of the six plant size classes, while the last column reports the mean of the entire sample. All figures are weighted by the appropriate sample weights to reflect their respective population.

3.2. Estimation Procedures

As stated on the outset, one of our objectives is to assess the differences, if any, in the technical relationships among factor inputs in the production in small and large U.S. manufacturing establishments. It is, therefore, necessary to clarify the terms “small” and “large”. We emphasize that these terms are relative, and it is impossible to offer a universally accepted definitions for small and large establishments. Thus, instead of drawing a definite line between small and large, following the MECS, we classify establishments into six employment size classes:

Size class 1: establishments with 20 to 49 employees.

Size class 2: establishments with 50 to 99 employees.

Size class 3: establishments with 100 to 249 employees.

Size class 4: establishments with 250 to 499 employees.

Size class 5: establishments with 500 to 999 employees.

Size class 6: establishments with 1,000 or more employees.

Note that data on establishments with less than 20 employees are not available in the MECS database. We estimate six separate translog production functions of the form (4), one for each of the six size classes. We also use the entire data set to estimate the overall production and use the resulting elasticity estimates to make inferences regarding the technical substitution behavior of the typical (average) manufacturing establishment. Finally, for the ten four digit industries that have sufficient observations, we estimate separate production functions for small and large plants within individual industries and evaluate the respective elasticities of substitution. Our estimation procedures are as follows.

The translog production function (4) is assumed to be symmetric and homogeneous of degree λ.[20] The following standard restrictions are imposed in the estimation:

$$\sum_{i=1}^{4} \alpha_i = \lambda, \quad \sum_{i=1}^{4} \beta_{ij} = 0, \quad \sum_{j=1}^{4} \beta_{ij} = 0, \ \textit{and} \ \sum_{i=1}^{4}\sum_{j=1}^{4} \beta_{ij} = 0, \qquad (13)$$

Monotonicity and convexity are not imposed, but are tested for after estimation. We append a random disturbance term u_i to the production function and to each share equation, $i = K, L, E, M$, and assume the resulting disturbance vector $u = \{u_K, u_L, u_E, u_M\}$ is multivariate normally distributed with mean vector zero and constant covariance matrix.

Since the cost shares sum to one, the disturbance covariance matrix of the share equation system (5) is singular. Therefore, the material cost share equation is dropped from the estimation. We use the iterative Zellner (1963) three stage least squares method to jointly estimate the production equation (4) and the remaining three equations (5).[21]

4. Empirical Results

4.1. The Estimated Production Functions

We report the parameter estimates (and the associated standard errors) of the model in

Table 2 to illustrate their statistical significance, although the individual estimates have little intuitive value because of the complexity of the translog form. In the Table, columns (1) - (6) present the estimates for the six regressions by size classes, while column (7) shows the estimates based on the entire data set. All regressions are estimated with two digit industry and region dummy variables to control for differences in industry and region.[22] From the Table, it can be seen that nearly all the parameter estimates are statistically significant; and they are highly so. This suggests that these estimates are quite precise and the estimated elasticities based on them are rather robust and reliable.

While we focus on elasticities of substitution, it is appropriate to report on whether or not the underlying production function is "well-behaved" because estimates of the elasticities under consideration are derived from it.[23] A well-behaved production function requires that output increases monotonically with all inputs and its isoquants are strictly quasi-concave. Monotonicity implies that all the estimated cost shares of inputs are non-negative. The concavity condition is satisfied if the bordered Hessian of first and second partial derivatives is negative semidefinite. Our estimated model based on the entire data set meets the regularity conditions fairly well. As shown at the bottom of Table 2, monotonicity conditions are met for 97.1 percent of data points, while concavity conditions are met for all but 302 (2.9 percent) of the 10,412 observations.

As for the regressions by plant size, we also find that the proportions of violations of both the convexity and monotonicity are also small (substantially less than 5% in most cases). Finally, we emphasize that, for all the estimated productions, there are no statistical violations of these conditions when evaluated at the means.

4.2. *Factor Substitution*

4.2.1. The Results from the Whole Sample

Table 3 reports estimates of four types of elasticities: price elasticities of demand (η), AES (σ), MES (σ^m) and shadow MES (σ^s). All these elasticity estimates are evaluated at the sample mean. We use actual cost shares, rather than estimated shares to evaluate the AES and shadow elasticities, as suggested by Anderson and Thursby (1986).[24] In the Table, columns (1) - (6) show the estimated elasticities for the six plant size classes which form a basis for our comparisons of the degrees of substitution (complementarity) among the four factor inputs in small and large establishment. The last column reports the elasticities evaluated based the estimates of the model using the entire data set. These later numbers represent the elasticities of a "typical" U.S. manufacturing plant.

Considering first, the estimates of price elasticities of demand for a typical U.S. manufacturing plant (column 7), we find that all the own-price elasticities (η_{ii}) are negative with absolute value greater than unity. This result implies that all four factors are quite responsive to changes in their own prices. In particular, energy is the most responsive to changes in its price, while capital is the least price responsive among the four primary inputs. A one percent increase in energy price leads to a 3.77 percent decline in the demand for energy. In contrast, the plant reduces its demand for capital by about 1.11 percent in response to a one percent increase in the price of capital. We also find that all the twelve CPE estimates based on the entire data set are positive, indicating that all inputs are pairwise substitutes in a typical U.S. manufacturing plant. We note, however, that except for the CPE estimates associated with materials, the CPE estimates are small. For example, $\eta_{KL,}$ η_{KE}, and η_{LE} equal 0.001, 0.011 and 0.025, respectively. Thus, based on CPE estimates, one would conclude that energy and capital, and energy and labor are, at best, weak substitutes.

Turning to the AES estimates, one can see that these estimates are identical to the price elasticity estimates in sign, but much large in magnitude. This is not surprising because, as already discussed above, the AES is simply equal to the price elasticity divided by a cost share which is always less than unity. These estimates clearly demonstrate that the AES is uninformative and misleading. Indeed, the large values of the AES estimates tend to lead one to overstate the degree of substitution/complementarity between any two inputs.

In brief, based on the estimates of the AES and CPE of demand one may conclude that all four inputs under study are pair-wise substitutes; but, the substitution relationships among capital, labor and energy are weak. Nevertheless, the AES and CPE do not tell the whole story because they do not measure the technical substitution relationships among inputs in production.

Examining the MES and shadow elasticity estimates, we find that all these estimates are positive and greater than unity. These figures indicate that all input ratios are highly sensitive to changes in any given input price as well as to changes in input price ratios. For example, the MES estimate indicates that, other things being equal, a one percent increase in the price of energy leads to a 3.78 percent increase in the capital energy ratio. Similarly, the estimated shadow elasticity implies that a one percent increase in the energy-capital price ratio leads to a 3.60 percent increase in the capital-energy ratio. In short, both the weighted (shadow) and unweighted MES estimates show that all four inputs (K, L, E, M) are pairwise substitutes in the production of a typical U.S. manufacturing establishment.

We now turn to factor substitution in small and large establishments. Again, starting with the estimates for the price elasticities of demand, we find that all the own-price elasticities are negative. In general, own-price elasticities for the smallest class of plants are somewhat less in magnitude. Examining the CPE estimates, we find that all elasticities associated with materials are positive and relatively similar across plant sizes. This result strongly suggests that capital and materials, labor and materials, and energy and materials behave as substitutes regardless of plant size. In contrast, the technical relationships between energy and capital, labor and capital, and energy and labor differ across size classes. For example, η_{EK} = 0.27 in plants with 20 - 49 employees (column 1), while that in plants with 500-999 employees equals -0.19 (column 5). The corresponding figures for η_{LK} are 0.02 and -0.30, respectively, and for η_{EL} are 0.59 and -0.31.

Similar results, of course, are obtained from the AES estimates because, by definition, the AES is equal to the price elasticity divided by an appropriate cost share. Thus, had we used the CPE and the AES as measures of factor substitution, we would have concluded that (1) energy and capital, and energy and labor are substitutes in small establishments, but they are complements in larger establishments and (2) small establishments are more flexible than large establishments in substituting capital and labor for energy.

Finally, the estimates for the MES and shadow elasticity show that all four factors are substitutable for one another in production, and that the degrees of substitution among the inputs are generally similar across all plant sizes. The elasticity estimates for the smallest size establishments are as large as those for the typical establishment. These results indicate that small establishments are as flexible as large establishments in substituting inputs in production.

4.2.2. Results by Industries

The above elasticity estimates are based on the whole sample. But, it is possible that plants of different sizes and across the many industries have different production functions and, therefore, differ in the degrees of factor substitution in response to changes in input prices. For this reason, for the industries that have sufficient data we estimate two separate production functions for small and large plants within an individual four digit industry and evaluate the respective elasticities of substitution. Our criterion in selecting only those industries that have at least 30 observations for both small and large plants, and which are among the 40 industries which the MECS sample is stratified by. Also, to maximize the number of industry that have sufficient data, within each four digit industry, we simply classify plants into two groups: "small" plants are those having less than 100 employees and "large" plants are those having 100 or more workers. With these criteria, we identify ten four digit industries that have sufficient data for estimating separate production functions of both small and large plants. These industries are as follows:

2011: Meat Packing
2033: Canned Fruits and Vegetables
2051: Bread, Cake and Related products
2631: Paperboard Mills
2819: Industrial Inorganic Chemicals
2821: Plastics Materials and Resins
2869: Industrial Organic Chemicals
3089: Plastics Products
3321: Gray and Doctile Iron Foundries
3841: Surgical and medical Instruments

Table 4 reports the estimated elasticities for the ten four digit industries. To conserve space, we report only the unweighted and weighted (shadow) Morishima elasticities of substitution. As expected the estimated elasticities vary across industries. Considering first the (unweighted) Morishima elasticities, we find this one-price-two-factor elasticity is highly asymmetric. For example, for small meat packing plants (2011), σ^M_{KE} = 1.50 while σ^M_{EK} = 0.98. For large meat packing plants σ^M_{KE} = 2.62, whereas σ^M_{EK} = -0.22. Of the 96 elasticity estimates, 93 are positive. This indicates that all four inputs are substitutes across industries and plant sizes, with two exceptions. First, for large meat packing plants σ^M_{EK} = -0.22, implying that when the price of capital increases, the demand for energy of large plants declines. That is, these plants fail to substitute energy for capital in response to an increase in the price of capital. Second, for small iron foundries (3321), the estimated values of σ^M_{EK} and σ^M_{EL} are -1.26 and -5.08 respectively. This implies that small plants in this industry are unable to substitute energy for capital and energy for labor in response to rises in the capital price and wages. Again, we note that the unweighted Morishima elasticity is a one-price-two-factor elasticity and, hence, it is not designed to capture the full substitution effect when the prices of the two inputs change simultaneously.

In contrast, all the 48 estimates of the shadow (weighted) Morishima elasticity are positive and substantially greater than one. These estimates indicate that all the four inputs (capital, labor, energy and materials) are substitutable in production; and they are highly so. For example, for meat packers (2011), an increase of one percent in the energy-capital price ratio would lead to an increase of 1.45 percent and 2.38 percent in the capital-energy quantity demanded by small plants and large plants, respectively.

Comparing the shadow Morishima elasticities between small and large plants, we find that in six of the ten industries under study, all the estimated elasticities for the two groups of plants are quite similar and are well above unity. In the remaining four industries, the shadow elasticities of substitution of large plants are consistently larger than those of small plants in meat packing (2011) and medical instruments (3841). However, the estimated elasticities for small plants are consistently greater than those for large plants in plastics (3089) and iron foundries (3321). Overall, we find that in a majority of industries small plants are as flexible as large plants in factor substitution. Small plant are even more flexible than large plants in some industries; but, of course, large plants are more flexible than small plants in some others.

4.3. Discussion

Our empirical results are easily summarized into two findings. First, using the appropriate plant-level data and the MES as a measure of factor substitution we find that, in a majority of industries, the degrees of substitution among the four inputs are similar across plants with different sizes. Second, we find that all four inputs: capital, labor, energy, and materials are highly substitutable in U.S. manufacturing production.

The first finding implies that, in U.S. manufacturing, small establishments are generally as flexible as large establishments in factor substitution. This finding supports Nguyen and Reznek's evidence (1993) based on plant-level data for five four digit industries. Also, as with Nguyen and Reznek, we find that small establishments appear to have no disadvantage over large establishments in adjusting their mixes of capital and labor in many industries. Thus, together with Nguyen and Reznek' s results, we conclude that, more often than not, large establishments have no advantage over small establishments in factor substitution; however, as expected, there is evidence suggesting that small establishments have the advantage in some industries and large plants have the advantage in some others.

In view of the long standing conflict among the estimates reported in previous studies, our finding that capital, labor, energy, and materials are all substitutes in production is also very important. This result supports the findings of Nguyen and Streitwieser (1997), Thompson and Taylor (1995), Nguyen and Reznek (1993), and Sickles and Streitwieser (1992). All these studies use the Morishima elasticity of substitution as a measure of input substitution in production. This suggests that previous conflicting elasticity of substitution estimates are the result of using the partial Allen elasticity of substitution. Had previous studies used the Morishima elasticity to measure factor substitution, they would have found that inputs are substitutes.

Finally, because capital and energy are found to be substitutes (rather than complements), our results *do not* support the view that the 1973 energy crisis is a significant, direct factor contributing to the post-1973 productivity slowdown. We note that our finding is not unique. In fact, Berndt (1982) conducted an exhaustive study on the impact of energy price increases on the productivity slowdown in U.S. manufacturing. He concluded that: "In summary, energy price increases are unlikely to have played a major direct or indirect role in the 1973-77 productivity slowdown in U.S. manufacturing" (p. 86).

5. Summary and Conclusions

In this article, we reexamine the empirical issue of factor substitution in U.S. manufacturing and we investigate the question of whether or not small and large plants differ in terms of utilizing production inputs. Our approach differs from earlier studies in that we use plant-level data (rather than aggregate data) to estimate the theoretically correct Morishima elasticity of substitution (rather than the Allen partial elasticity). Plant-level data are unquestionably more appropriate for measuring technical substitution relationships among factors of production, while the Morishima elasticity of substitution has been proven as an exact measure of factor substitution in terms of adjustments of inputs along an isoquant in response to factor price changes.

Our principal findings are that (1) capital, labor, energy and materials are substitutes in U.S. manufacturing production and (2) except for some industries, plants of different sizes are very similar in utilizing inputs in production. The first result resolves the long-standing conflict among the estimates reported in previous studies regarding the substitution relationships among factors of production. Conflicting estimates reported in previous studies are the result of estimating inappropriate measures of elasticity of substitution with aggregate data. Our evidence of factor substitution suggests that the 1973 energy crisis is unlikely to be a significant contributing factor to the post-1973 productivity slowdown in U.S. manufacturing.

Our finding that small establishments are as flexible as large establishments in factor substitution, together with the capital-energy substitution evidence, suggests that policies resulting in rising energy prices would not cause negative effect on U.S. manufacturing.

Neither large nor small production establishments would suffer directly from such policies.

In concluding, we note that our results are based on cross-section data for a single year. It is important to examine the robustness of these results by using time-series micro data. In particular, the data used should include the years in which there were substantial energy price increases such as those in 1973 and 1979.

ENDNOTES

1. All micro data collected by the U.S. Bureau of the Census is confidential and cannot be released for public use. However, academics and interested researchers can obtain access to the micro data through the Bureau's research fellowship program or the research program at the Center for Economic Studies. For more information on access to the micro data, contact Mary Streitwieser, Center for Economic Studies, U.S. Bureau of the Census at (301) 457-1837, or by e-mail: mstreitw@ces.census.gov.

2. These five industries are: (1) women's, misses' and juniors' dresses, SIC 2335, (2) wood household furniture, SIC 2511, (3) newspapers, SIC 2711, (4) electronic computing equipment, SIC 3573, and (5) radio and television transmission, signaling, and detection equipment, SIC 3662.

3. For example, Hisnanick and Kyer (1995) extended the model to include five inputs in which energy are disaggregated into two inputs: electricity and non-electricity. Morrison (1993) divided capital into three components: a "high tech" capital aggregate of office and information technology capital, an equipment aggregate, and a structure aggregate. Berndt and White (1978) classified labor into two categories: blue collar labor and white collar labor.

4. For example, Magnus (1979) used a generalized Cobb-Douglas cost function, while Berndt and Khaled (1979) applied a generalized Box-Cox function. Chung (1987) estimated elasticities via a truncated, single translog cost-share equation.

5. Field and Grebenstein (1980), for example, argued that studies such as those by Griffin and Gregory (1976) and Pindyck (1979), which measured capital costs as a residual, inappropriately capture the influence of both the cost of reproducible capital and working capital. Estimating a homothetic translog cost function in which capital is divided into reproducible capital (structure and equipment) and working capital, Field and Grebenstein found that reproducible capital and energy are complement, while energy and working capital are substitutes. Nguyen and Andrews (1989) argued that energy aggregates constructed using different methods yield substantially different energy elasticities. Their empirical results showed that Divisia energy aggregates out perform BTU-based aggregates.

6. Instead of using data for total U.S. manufacturing, such as those used by Berndt and Wood (1975), Field and Grebenstein (1980) used state-level data for 10 U.S. manufacturing two digit industry groups. With these data, they obtained mixed results: for industry groups 24, 28, and 33, energy and physical capital were found to be complements. For the remaining groups the results were inconclusive. Denny et al. (1981) used time-series data for 18 U.S. manufacturing two digit industries (1948-71) and 18 Canadian manufacturing industry groups (1962-75). Their results were also mixed: for both U.S. and Canada, energy and capital were substitutes in the food industry, but they were complements in the tobacco industry.

7. Some product composition effects will exist at the plant level also, but to a lesser degree than with aggregate data. Over half of the plants in our sample produce a single five digit product; another 35 percent produce only two or three products.

8. Also, see Miller (1986) for additional arguments against aggregate data.

9. The MES was developed independently by Morishima (1967) and Blackorby and Russell (1975).

10. An establishment is defined as a single plant or factory in which manufacturing operations are performed. Generally speaking, an establishment is a plant. However, in some instances a plant is broken down into a number of establishments, each constituting a unique record in our data, when distinctly different lines of activity are performed at one location and if the activities are substantial in size.

11. The production function model assumes full equilibrium and that inputs are exogenous. We recognize the assumption of exogenous inputs probably does not hold; however, we lack establishment level instruments to make the standard instrumental variables correction. There is a stronger argument that input prices on exogenous from cost, suggesting that a cost based model is more appropriate. Unfortunately, data on input prices required for the estimation of a cost function are not available at the plant level. Empirically, Burgess (1975) found that the translog production function specification is superior to the translog cost function in terms of goodness of fit and smaller standard errors of the parameter estimates.

12. The translog function was developed by Christensen, Jorgenson and Lau (1971). Applied studies using this form include Berndt and Wood (1975), Griffin and Gregory (1976), Field and Grebenstein (1980), Nguyen and Andrews (1989), Hisnanik and Kyer (1995) and other studies of factor substitution. Other flexible functional forms are also available, including the extended generalized Cobb-Douglas form (Magnus, 1979), the symmetric generalized McFadden form (McFadden, 1978, and Diewert and Wales, 1987). We choose the translog function because it is the most widely used in empirical studies of factor substitution.

13. See Allen, 1938, p. 504.

14. See Nguyen and Streitwieser (1997) for details.

15. For reviews of the literature on small and large firms, see Storey (1994) and Acs (1995, 1996).

16. Acs, Zoltan J. and Lee Preston (1997), pg 2.

17. We use book values as a proxy for capital input because other data are not available. We note, however, that Doms' (1996) and Dwyer's (1997) work — which also uses the Census Bureau's micro data — indicate that book value is a reasonable proxy for capital inputs.

18. For a fuller description of the MECS and ASM data sets, as well as construction of the variables, see Nguyen and Streitwieser (1997).

19. We also omit plants in the petroleum refining industry (SIC 2911) because a significant, but unknown, portion of their fuel is derived as a by-product of the processes used to convert feedstock to marketed products. While other industries may derived some of their fuel as a result of the production process, it is not as severe a problems as in the refining industry.

20. Most previous studies assume homogeneity of degree one by setting $\lambda = 1$.

21. Diewert (1972) suggests that one should include the translog production function (or cost function) with the cost share equations for efficient estimation.

22. The MECS sample is stratified at the two digit industry level, with the exception of 40 four digit industries and two three digit industries. This stratification scheme precludes industry dummy variables below the two digit level.

23. Wales (1977) noted, however, that the rejection of either the monotonicity or the concavity condition does not necessarily imply that the elasticity estimates are incorrect.

24. Most previous studies evaluated elasticities of substitution at the means of fitted shares. However, Anderson and Thursby (1986) showed it is more appropriate to use actual shares. In particular, they found that "a normal distribution for the AES (Allen elasticity of substitution) is appropriate if the estimator uses the <u>means</u> of the <u>actual</u> factor shares." (p. 652). However, our mean estimated factor shares are very close to the actual values, as are the derived elasticities.

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TABLE 1
MEAN VARIABLE VALUES
BY EMPLOYMENT SIZE CLASS

	Weighted Sample — By Employment Size Class						
	20- 50	50-99	100-249	250-499	500-999	>=1000	All
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
N	1,722	1,486	2,713	2,101	1,411	979	10,412
Output ($Million)	7.33	22.69	40.85	76.27	151.16	629.49	110.16
Capital ($Million)	2.83	8.58	18.94	35.88	78.87	267.35	49.69
Labor (Thousand Hrs)	64.81	183.03	400.88	822.35	1,589.42	5,939.68	1,081.11
Energy (Million Btu)	51.93	166.69	375.74	564.54	1,058.91	2,252.56	599.50
Materials ($Million)	4.28	13.25	22.09	37.85	70.86	301.28	53.92
Capital Cost Share	0.26	0.25	0.25	0.26	0.28	0.27	0.26
Labor Cost Share	0.25	0.23	0.23	0.25	0.25	0.27	0.25
Energy Cost Share	0.04	0.04	0.04	0.03	0.03	0.02	0.04
Material Cost Share	0.45	0.47	0.47	0.45	0.44	0.43	0.46
Total Employment	26	74	165	356	687	2,544	462

TABLE 2
REGRESSION PARAMETER ESTIMATES
BY EMPLOYMENT SIZE CLASS

Parameter	Weighted Sample — By Employment Size Class						
	20- 50	50-99	100-249	250-499	500-999	>=1000	All
α_o	0.312 (0.049)	0.603 (0.072)	0.598 (0.050)	0.742 (0.055)	1.033 (0.085)	0.410 (0.077)	0.363 (0.019)
α_K	0.187 (0.009)	0.220 (0.008)	0.178 (0.006)	0.149 (0.006)	0.197 (0.008)	0.126 (0.008)	0.195 (0.003)
α_L	-0.090 (0.010)	-0.150 (0.008)	-0.077 (0.006)	-0.068 (0.006)	-0.073 (0.007)	-0.012 (0.009)	-0.098 (0.004)
α_E	0.025 (0.002)	0.024 (0.002)	0.026 (0.002)	0.016 (0.002)	0.013 (0.002)	0.019 (0.002)	0.024 (0.001)
α_M	0.894 (0.006)	0.901 (0.007)	0.852 (0.005)	0.867 (0.005)	0.811 (0.008)	0.857 (0.008)	0.889 (0.003)
β_{KK}	0.041 (0.002)	0.052 (0.002)	0.049 (0.001)	0.049 (0.002)	0.058 (0.002)	0.035 (0.002)	0.047 (0.001)
β_{LL}	0.107 (0.002)	0.118 (0.002)	0.095 (0.001)	0.093 (0.001)	0.093 (0.002)	0.089 (0.002)	0.108 (0.001)
β_{EE}	0.013 (0.0003)	0.014 (0.0004)	0.015 (0.0003)	0.014 (0.0003)	0.015 (0.0004)	0.015 (0.001)	0.014 (0.0001)
β_{MM}	0.167 (0.001)	0.175 (0.002)	0.175 (0.001)	0.187 (0.001)	0.181 (0.002)	0.182 (0.002)	0.171 (0.001)
β_{KL}	0.009 (0.002)	-0.0004 (0.001)	0.014 (0.001)	0.021 (0.001)	0.013 (0.002)	0.028 (0.002)	0.007 (0.001)
β_{KE}	-0.002 (0.0004)	-0.0002 (0.0005)	-0.0004 (0.0004)	-0.003 (0.0004)	-0.002 (0.0005)	-0.001 (0.001)	-0.001 (0.0002)
β_{KM}	-0.048 (0.001)	-0.052 (0.001)	-0.062 (0.001)	-0.068 (0.001)	-0.069 (0.001)	-0.062 (0.002)	-0.053 (0.003)
β_{LE}	-0.004 (0.0004)	-0.004 (0.0004)	-0.005 (0.0004)	-0.003 (0.0003)	-0.003 (0.0005)	-0.005 (0.001)	-0.004 (0.0002)
β_{LM}	-0.112 (0.001)	-0.113 (0.001)	-0.104 (0.001)	-0.112 (0.001)	-0.103 (0.001)	-0.112 (0.002)	-0.111 (0.0005)

β_{EM}	-0.007 (0.0003)	-0.010 (0.0004)	-0.009 (0.0004)	-0.007 (0.0003)	-0.009 (0.0006)	-0.009 (0.001)	-0.008 (0.0002)
λ	1.016 (0.004)	0.996 (0.007)	0.979 (0.005)	0.964 (0.005)	0.949 (0.007)	0.989 (0.006)	1.010 (0.002)
Convexity Violations	126 (7.3%)	116 (7.8%)	45 (1.7%)	12 (0.6%)	10 (0.7%)	2 (0.2%)	302 (2.9%)
Monotonicity Violations	218 (3.2%)	213 (3.6%)	238 (2.2%)	117 (1.4%)	86 (1.5%)	89 (2.3%)	760 (1.8%)
N	1,722	1,486	2,713	2,101	1,411	979	10,412

Standard errors are given in parentheses. All regression include industry and region dummy variables.

TABLE 3
ELASTICITIES OF SUBSTITUTION
BY EMPLOYMENT SIZE CLASS

Elasticity	Weighted Sample — By Employment Size Class						
	20- 50	50-99	100-249	250-499	500-999	>=1000	All
PDemand							
η_{KK}	-1.057	-1.190	-1.189	-1.320	-1.282	-1.097	-1.106
η_{LL}	-1.518	-1.836	-1.812	-2.148	-2.100	-2.001	-1.615
η_{EE}	-3.756	-3.887	-3.903	-3.453	-3.857	-5.234	-3.766
η_{MM}	-2.230	-2.166	-2.112	-2.878	-2.873	-2.687	-2.183
η_{KL}	0.034	0.021	-0.157	-0.442	-0.295	-0.297	0.001
η_{KE}	0.019	-0.024	-0.010	0.033	-0.014	-0.003	0.011
η_{KM}	1.003	1.193	1.356	1.729	1.592	1.397	1.094
η_{LK}	0.023	0.015	-0.140	-0.398	-0.300	-0.293	0.0004
η_{LE}	0.028	0.012	0.058	0.018	-0.024	0.047	0.025
η_{LM}	1.467	1.809	1.893	2.528	2.424	2.246	1.590
η_{EK}	0.273	-0.278	-0.117	0.425	-0.191	-0.041	0.144
η_{EL}	0.586	0.196	0.791	0.258	-0.306	0.676	0.454
η_{EM}	2.896	3.968	3.229	2.770	4.354	4.598	3.168
η_{MK}	0.662	0.633	0.762	1.048	1.061	0.937	0.679
η_{ML}	1.433	1.350	1.200	1.700	1.591	1.532	1.356
η_{ME}	0.136	0.183	0.151	0.131	0.221	0.218	0.148
Allen							
σ_{KK}	-4.295	-5.211	-4.743	-5.064	-4.563	-3.923	-4.492
σ_{LL}	-4.171	-5.713	-6.411	-7.429	-7.594	-7.043	-4.772
σ_{EE}	-215.475	-196.124	-187.734	-170.105	-180.640	-265.158	-202.867
σ_{MM}	-5.986	-5.031	-4.736	-6.695	-6.819	-6.449	-5.499
σ_{KL}	0.094	0.066	-0.557	-1.529	-1.069	-1.047	0.002

σ_{KE}	1.113	-1.215	-0.466	1.630	-0.678	-0.146	0.585
σ_{KM}	2.692	2.771	3.040	4.021	3.778	3.353	2.757
σ_{LE}	1.611	0.611	2.799	0.892	-1.108	2.381	1.340
σ_{LE}	3.937	4.201	4.245	5.879	5.753	5.392	4.006
σ_{EM}	7.772	9.219	7.240	6.443	10.336	11.036	7.983
Morishima							
σ^m_{KL}	1.552	1.857	1.654	1.706	1.804	1.703	1.616
σ^m_{KE}	3.776	3.863	3.893	3.486	3.843	5.231	3.777
σ^m_{KM}	3.233	3.359	3.468	4.607	4.464	4.084	3.276
σ^m_{LK}	1.080	1.205	1.049	0.921	0.982	0.804	1.106
σ^m_{LE}	3.785	3.899	3.961	3.471	3.834	5.281	3.791
σ^m_{LM}	3.697	3.974	4.005	5.406	5.296	4.933	3.772
σ^m_{EK}	1.331	0.913	1.072	1.745	1.091	1.056	1.249
σ^m_{EL}	2.104	2.032	2.603	2.406	1.793	2.677	2.069
σ^m_{EM}	5.126	6.134	5.341	5.649	7.227	7.285	5.351
σ^m_{MK}	1.719	1.823	1.951	2.368	2.343	2.034	1.784
σ^m_{ML}	2.951	3.186	3.011	3.847	3.690	3.532	2.971
σ^m_{ME}	3.892	4.070	4.053	3.584	4.078	5.452	3.914
Shadow							
σ^s_{KL}	1.270	1.476	1.334	1.293	1.396	1.250	1.320
σ^s_{KE}	3.614	3.628	3.677	3.360	3.649	4.955	3.599
σ^s_{KM}	2.321	2.355	2.497	3.213	3.192	2.857	2.355
σ^s_{LE}	3.708	3.791	3.868	3.401	3.688	5.112	3.701
σ^s_{LM}	3.320	3.523	3.397	4.474	4.327	4.100	3.340
σ^s_{EM}	3.947	4.161	4.111	3.677	4.230	5.534	3.978
N	1722	1486	2713	2101	1411	979	10412

TABLE 4
ELASTICITIES OF SUBSTITUTION
BY INDUSTRY AND EMPLOYMENT SIZE CLASS*

Elasticity	Meat Packing-2011		Canned Fruits & Vegetables-2033		Bread, Cake & Related-2051		Paperboard Mills-2631	
	small	large	small	large	small	large	small	large
Morishima								
σ^m_{KL}	2.242	12.948	4.545	2.716	1.560	1.725	4.160	5.391
σ^m_{KE}	1.499	2.616	1.549	2.168	2.202	3.882	1.868	6.819
σ^m_{KM}	1.531	7.116	3.070	4.571	8.016	6.043	7.174	8.656
σ^m_{LK}	0.993	0.170	0.684	0.908	0.766	0.897	1.494	1.118
σ^m_{LE}	1.424	1.668	1.587	2.253	2.253	3.894	2.056	4.310
σ^m_{LM}	2.855	20.842	6.893	6.294	8.759	6.859	9.651	15.438
σ^m_{EK}	0.983	-0.219	1.179	1.723	0.769	1.590	1.365	1.062
σ^m_{EL}	1.413	1.770	5.101	3.863	2.408	2.736	4.452	0.880
σ^m_{EM}	2.876	21.130	2.886	3.869	8.601	7.324	7.384	18.923
σ^m_{MK}	1.127	2.599	1.570	3.114	3.113	3.016	2.797	2.071
σ^m_{ML}	2.612	17.065	6.002	4.127	6.191	4.639	7.878	9.031
σ^m_{ME}	1.534	3.016	1.572	2.213	2.474	3.996	2.526	9.761
Shadow								
σ^s_{KL}	1.594	6.506	3.169	2.166	1.062	1.300	2.966	3.818
σ^s_{KE}	1.453	2.383	1.524	2.148	2.069	3.780	1.728	5.402
σ^s_{KM}	1.181	3.076	2.047	3.657	4.825	4.351	5.291	4.958
σ^s_{LE}	1.423	1.676	2.004	2.409	2.262	3.845	2.827	3.078
σ^s_{LM}	2.647	17.469	6.201	4.574	7.411	5.647	8.796	11.034
σ^s_{EM}	1.555	3.205	1.616	2.259	2.793	4.114	4.166	11.624
N	48	102	37	115	43	199	38	91

Elasticity	Industrial Inorganics-2819		Plastic Material & Resins-2821		Industrial Organics-2869		Plastics-3089	
	small	large	small	large	small	large	small	large
Morishima								
σ^m_{KL}	2.436	3.472	2.578	4.528	3.460	2.818	2.095	1.665
σ^m_{KE}	1.774	1.371	2.150	2.263	8.204	2.701	2.460	1.649
σ^m_{KM}	3.475	3.428	3.912	3.417	3.072	4.959	6.718	5.746
σ^m_{LK}	1.431	1.543	0.839	0.737	1.476	1.126	1.358	1.118
σ^m_{LE}	1.603	1.309	2.017	2.141	8.786	2.272	2.365	1.585
σ^m_{LM}	4.651	5.420	5.784	7.331	4.474	7.080	7.551	6.357
σ^m_{EK}	0.855	1.735	0.855	1.393	3.032	1.931	0.693	1.416
σ^m_{EL}	1.575	3.384	1.652	4.377	9.892	1.544	0.245	1.334
σ^m_{EM}	5.255	3.154	6.133	4.439	1.813	7.003	10.335	6.311
σ^m_{MK}	2.160	2.018	2.381	1.904	2.128	3.111	3.072	2.867
σ^m_{ML}	3.287	4.876	3.909	5.917	4.526	4.364	5.116	4.338
σ^m_{ME}	2.238	1.378	2.350	2.388	8.083	3.003	3.085	1.855
Shadow								
σ^s_{KL}	2.061	2.733	1.962	3.350	2.713	2.287	1.675	1.359
σ^s_{KE}	1.623	1.429	2.056	2.168	7.894	2.619	2.256	1.625
σ^s_{KM}	2.650	2.685	2.872	2.400	2.545	3.843	4.537	3.923
σ^s_{LE}	1.596	1.789	1.972	2.621	8.892	2.121	2.176	1.564
σ^s_{LM}	3.643	5.071	4.295	6.173	4.509	4.991	6.264	5.194
σ^s_{EM}	2.553	1.633	2.484	2.505	7.780	3.294	3.667	2.134
N	147	70	143	97	95	152	71	103

Elasticity	Iron Foundries-3321		Medical & Surgical Instruments-3841	
	small	large	small	large
Morishima				
σ^m_{KL}	2.648	1.016	1.210	2.254
σ^m_{KE}	6.153	1.758	2.114	2.204
σ^m_{KM}	22.503	10.047	3.392	6.260
σ^m_{LK}	0.499	1.414	0.939	1.242
σ^m_{LE}	5.255	1.739	2.112	2.193
σ^m_{LM}	25.551	9.668	3.664	7.282
σ^m_{EK}	-1.262	1.663	1.940	1.737
σ^m_{EL}	-5.081	1.372	2.499	2.454
σ^m_{EM}	37.658	9.786	2.276	6.526
σ^m_{MK}	5.323	4.315	1.871	3.085
σ^m_{ML}	14.301	5.795	2.774	5.375
σ^m_{ME}	11.681	2.711	2.070	2.258
Shadow				
σ^s_{KL}	1.333	1.271	1.056	1.729
σ^s_{KE}	4.503	1.731	2.107	2.188
σ^s_{KM}	13.168	6.444	2.592	4.693
σ^s_{LE}	3.668	1.674	2.124	2.201
σ^s_{LM}	20.714	7.783	3.259	6.377
σ^s_{EM}	16.716	4.013	2.078	2.401
N	30	91	45	88

*Small = 20-99 employees; large = 100 or more employees.