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# I. Labor and Multifactor Productivity by Industry

# 1 U.S. Productivity Growth by Industry, 1947–73

Frank M. Gollop and Dale W. Jorgenson

The objective of this paper is to describe and analyze postwar patterns of productivity growth by industry for the U.S. economy. In section 1.1 we present a model of production and technical change that permits an analysis of sources of growth in output for individual industrial sectors. The model includes a production function for each sector, giving output as a function of intermediate input, capital input, labor input, and time. The model also includes conditions for producer equilibrium. Given the production function and the conditions for producer equilibrium, we can generate index numbers for sectoral output, sectoral capital, labor, and intermediate input, the corresponding prices, and sectoral productivity.

We present disaggregated measures of labor input in section 1.2. These measures are index numbers constructed from detailed data on labor input for each year, cross-classified by age, sex, education, occupation, and class of worker for each sector. We present disaggregated measures of capital input in section 1.3. These measures are index numbers constructed from detailed data on capital input for each year, cross-classified by type of asset and legal form of organization for each

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industrial sector. In section 1.4 we present annual measures of output and intermediate input for each industrial sector. Finally, we combine sectoral intermediate input, capital input, labor input, and output into an index of productivity for each sector for the period 1947–73.

## 1.1 Sectoral Production and Technical Change

### 1.1.1 Technical Change

Our methodology for productivity measurement is based on a model of production and technical change. The point of departure for this model is a production function for each industrial sector, giving output as a function of intermediate input, capital input, labor input, and time. To analyze substitution among primary factors of production and intermediate goods, we combine the production function for each sector with necessary conditions for producer equilibrium for that sector. These conditions take the form of equalities between the shares of each input in the value of output of each sector and the elasticity of sectoral output with respect to the corresponding input. The elasticities depend on inputs and time, the variables that enter the production function for each sector. To analyze changes in substitution possibilities over time, we consider the rate of technical change for each sector, defined as the rate of growth of the output of that sector, holding all inputs into the sector constant. The rate of technical change, like the elasticities of sectoral output with respect to sectoral inputs, depends on inputs and time.

development of these data would have been impossible. Finally, we wish to acknowledge the able research assistance of David Carvalho, Blake Evernden, and David Robinson.

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We consider production under constant returns to scale for each sector, so that a proportional increase in all inputs results in a proportional change in sectoral output. Under constant returns to scale the sum of elasticities of each sector's output with respect to all inputs is equal to unity, so that the value shares of all inputs sum to unity for each sector. The necessary conditions for producer equilibrium for each sector can be combined with growth rates of intermediate input, capital input, labor input, and output to produce an index number for the sectoral rate of technical change that depends on the prices and quantities of inputs and outputs for the sector.

Our sectoral models of production and technical change are based on production functions $\{F^i\}$ for each of the $n$ sectors, characterized by constant returns to scale:

$$Z_i = F^i\,(X_i, K_i, L_i, T), \qquad (i = 1, 2, \ldots, n),$$

where $\{Z_i\}$ is the set of outputs, $\{X_i\}$ is the set of intermediate inputs, $\{K_i\}$ is the set of capital inputs, and $\{L_i\}$ is the set of labor inputs for all $n$ sectors, and $T$ is time. Denoting the prices of outputs by $\{q_i\}$, the prices of intermediate inputs by $\{p^i{}_X\}$, the prices of capital inputs by $\{p^i{}_K\}$, and the prices of labor inputs by $\{p^i{}_L\}$, we can define the shares of intermediate input, say $\{v^i{}_X\}$, capital input, say $\{v^i{}_K\}$, and labor input, say $\{v^i{}_L\}$, in the value of output for each of the sectors by

$$v^i{}_X = \frac{p^i{}_X\, X_i}{q_i\, Z_i},$$

$$v^i{}_K = \frac{p^i{}_K\, K_i}{q_i\, Z_i},$$

$$v^i{}_L = \frac{p^i{}_L\, L_i}{q_i\, Z_i}, \qquad (i = 1, 2, \ldots, n).$$

Necessary conditions for producer equilibrium for each sector are given by equalities between the value shares of each input into the sector and the elasticity of output with respect to that input:

$$v^i{}_X = \frac{\partial \ln Z_i}{\partial \ln X_i}\,(X_i, K_i, L_i, T),$$

$$v^i{}_K = \frac{\partial \ln Z_i}{\partial \ln K_i}\,(X_i, K_i, L_i, T),$$

$$v^i{}_L = \frac{\partial \ln Z_i}{\partial \ln L_i}\,(X_i, K_i, L_i, T), \qquad (i = 1, 2, \ldots, n).$$

The production function for each industrial sector is defined in terms of sectoral output, intermediate input, capital input, and labor input. Under constant returns to scale for each sector, the elasticities and the value shares for all three inputs sum to unity. Each of the inputs is an aggregate that depends on the quantities of individual intermediate inputs, capital inputs, and labor inputs to the sector. Constant returns to scale imply that the aggregates for each sector are characterized by constant returns to scale; proportional changes in all the inputs that comprise each aggregate input result in proportional changes in the aggregate:

$$X_i = X_i\,(X_{1i}, X_{2i}, \ldots, X_{ni}),$$
$$K_i = K_i\,(K_{1i}, K_{2i}, \ldots, K_{pi}),$$
$$L_i = L_i\,(L_{1i}, L_{2i}, \ldots, L_{qi}), \qquad (i = 1, 2, \ldots, n),$$

where $\{X_{ji}\}$ is the set of $n$ intermediate inputs from the $j$th sector ($j = 1, 2, \ldots, n$), $\{K_{ki}\}$ the set of $p$ capital inputs, and $\{L_{li}\}$ the set of $q$ labor inputs, all into the $i$th sector ($i = 1, 2, \ldots, n$).

Denoting the prices of capital inputs by $\{p^i_{Kk}\}$ and the prices of labor inputs by $\{p^i_{Ll}\}$, we can define the shares of the $n$ intermediate inputs, say $\{v^i_{Xj}\}$, in the value of intermediate input, the shares of the $p$ capital inputs, say $\{v^i_{Kk}\}$, in the value of capital input, and the shares of the $q$ labor inputs, say $\{v^i_{Ll}\}$, in the value of labor input in the $i$th sector ($i = 1, 2, \ldots, n$) by

$$v^i_{Xj} = \frac{q_j X_{ji}}{p^i_X X_i}, \qquad (i, j = 1, 2, \ldots, n),$$

$$v^i_{Kk} = \frac{p^i_{Kk} K_{ki}}{p^i_K K_i}, \qquad (i = 1, 2, \ldots, n; k = 1, 2, \ldots, p),$$

$$v^i_{Ll} = \frac{p^i_{Ll} L_{li}}{p^i_L L_i}, \qquad (i = 1, 2, \ldots, n; l = 1, 2, \ldots, q).$$

Necessary conditions for producer equilibrium for each sector are given by equalities between the shares of each individual input in the value of the corresponding aggregate and the elasticities of the aggregate with respect to the individual inputs:

$$v^i_{Xj} = \frac{\partial \ln X_i}{\partial \ln X_{ji}}(X_{1i}, X_{2i}, \ldots X_{ni}),$$

$$v^i_{Kk} = \frac{\partial \ln K_i}{\partial \ln K_{ki}}(K_{1i}, K_{2i}, \ldots, K_{pi}),$$

$$v^i_{Ll} = \frac{\partial \ln L_i}{\partial \ln L_{li}}(L_{1i}, L_{2i}, \ldots, L_{qi}), \quad (i = 1, 2, \ldots, n).$$

Under constant returns to scale, the elasticities and the value shares sum to unity for each of the three aggregates for each sector.

Finally, we can define rates of technical change, say $\{v^i_T\}$, for all $n$ sectors, as rates of growth of output with respect to time, holding intermediate input, capital input, and labor input constant:

$$v^i_T = \frac{\partial \ln Z_i}{\partial T}(X_i, K_i, L_i, T), \qquad (i = 1, 2, \ldots, n).$$

Under constant returns to scale the rate of technical change for each sector can be expressed as the rate of growth of the corresponding sectoral output less a weighted average of the rates of growth of intermediate input, capital input, and labor input into the sector, where the weights are given by the corresponding value shares:

$$\begin{aligned} \frac{d \ln Z_i}{d T} &= \frac{\partial \ln Z_i}{\partial \ln X_i}\frac{d \ln X_i}{d T} + \frac{\partial \ln Z_i}{\partial \ln K_i}\frac{d \ln K_i}{d T} \\ &\quad + \frac{\partial \ln Z_i}{\partial \ln L_i}\frac{d \ln L_i}{d T} + \frac{\partial \ln Z_i}{\partial T}, \\ &= v^i_X \frac{d \ln X_i}{d T} + v^i_K \frac{d \ln K_i}{d T} + v^i_L \frac{d \ln L_i}{d T} \\ &\quad + v_{iT}, \qquad (i = 1, 2, \ldots, n). \end{aligned}$$

We refer to the expressions $\{v^i_T\}$ as the *Divisia quantity indexes of sectoral rates of technical change.*

The Divisia quantity indexes of sectoral technical change are defined in terms of sectoral aggregates for intermediate input, capital input, and labor input. Under constant returns to scale the rate of growth of each sectoral aggregate can be expressed as a weighted average of rates of growth of its components, where weights are given by the corresponding value shares:

$$\begin{aligned} \frac{d \ln X_i}{dT} &= \Sigma v^i_{Xj} \frac{d \ln X_{ji}}{dT}, \\ \frac{d \ln K_i}{dT} &= \Sigma v^i_{Kk} \frac{d \ln K_{ki}}{dT}, \\ \frac{d \ln L_i}{dT} &= \Sigma v^i_{Ll} \frac{d \ln L_{li}}{dT}, \qquad (i = 1, 2, \ldots, n). \end{aligned}$$

We refer to these expressions $\{X_i, K_i, L_i\}$ as *Divisia indexes of sectoral intermediate input, capital input, and labor input.*[1]

If the production function for each individual sector gives output $Z_i$

1. These quantity indexes and the analogous price indexes discussed below were introduced by Divisia (1925, 1928, 1952). The Divisia index of technical change was introduced by Solow (1957) and has been discussed by Hulten (1973*a*), Jorgenson and Griliches (1967, 1971), Merrilees (1971), Nelson (1973), Richter (1966), and Usher (1974).

as a function of a sectoral aggregate for input, say $W_i$, we can write this function in the form

$$Z_i = G^i\,[W_i(X_i, K_i, L_i), T], \qquad (i = 1, 2, \ldots, n),$$

where input is homogeneous of degree one in intermediate input $X_i$, capital input $K_i$, and labor input $L_i$ for the sector. The production function $G^i$ is homogeneous of degree one in input $W_i$, so that sectoral technical change is *Hicks-neutral* and we can rewrite the function in the form

$$Z_i = A_i(T) \cdot W_i(X_i, K_i, L_i), \qquad (i = 1, 2, \ldots, n).$$

The sectoral rate of technical change is independent of intermediate, capital, and labor input and depends only on time:

$$v^i_T = \frac{d \ln A_i(T)}{dT}, \qquad (i = 1, 2, \ldots, n);$$

similarly, sectoral input is independent of time and depends only on intermediate, capital, and labor input. The rate of growth of sectoral input can be expressed as a weighted average of rates of growth of these inputs:

$$\frac{d \ln W_i}{dT} = v^i_X \frac{d \ln X_i}{dT} + v^i_K \frac{d \ln K_i}{dT} + v^i_L \frac{d \ln L_i}{dT}, \qquad (i = 1, 2, \ldots, n).$$

We refer to this expression $\{W_i\}$ as the *Divisia index of sectoral input.*[2]

Under constant returns to scale the existence of a sectoral aggregate for input is equivalent to Hicks neutrality of sectoral technical change. We do not require the existence of such an aggregate in constructing an index of sectoral technical change; equivalently, we do not require that sectoral technical change be Hicks-neutral. Our disaggregated production account includes data on output, intermediate input, capital input, and labor input in current and constant prices and data on sectoral productivity for each sector. We do not present data on aggregate input for each sector, and the assumption of Hicks neutrality is not employed in the construction of our indexes of sectoral technical change.

### 1.1.2 Duality

Under constant returns to scale the necessary conditions for producer equilibrium imply that the value of output is equal to the sum of the values of intermediate, capital, and labor input into each sector:

2. The definition of technical change that is neutral in the sense that the ratio of marginal products of capital and labor for any ratio of capital and labor input is independent of time is due to Hicks (1932). This definition is generalized to more than two inputs by Burmeister and Dobell (1969).

$$q_i Z_i = p^i_X X_i + p^i_K K_i + p^i_L L_i, \qquad (i = 1, 2, \ldots, n).$$

Our data on output, intermediate input, capital input, and labor input in current prices for each sector satisfy this equality as an accounting identity. Given this equality for each sector, equalities between the value shares of each input into the sector and the elasticity of sectoral output with respect to that input, we can express the price of sectoral output as a function, say $P^i$, of the prices of intermediate input, capital input, labor input, and time:

$$q_i = P^i(p^i_X, p^i_K, p^i_L, T), \qquad (i = 1, 2, \ldots, n).$$

We refer to these functions as the *sectoral price functions.*[3]

Under constant returns to scale the values of intermediate, capital, and labor input are equal to the sum of the values of their components:

$$p^i_X X_i = \Sigma q_j X_{ji},$$
$$p^i_K K_i = \Sigma p^i_{Kk} K_{ki},$$
$$p^i_L L_i = \Sigma p^i_{Ll} L_{li}, \qquad (i = 1, 2, \ldots, n).$$

Our data on the components of intermediate, capital, and labor input for each sector satisfy these equalities as accounting identities. The prices of intermediate, capital, and labor input are functions of the prices of their components:

$$p^i_X = p^i_X(q_1, q_2, \ldots, q_n),$$
$$p^i_K = p^i_K(p^i_{K1}, p^i_{K2}, \ldots, p^i_{Kp}),$$
$$p^i_L = p^i_L(p^i_{L1}, p^i_{L2}, \ldots, p^i_{Lq}), \qquad (i = 1, 2, \ldots, n).$$

We can express the rate of growth of the price index for each sectoral aggregate as a weighted average of the rates of growth of its components:

$$\frac{d \ln p^i_X}{dT} = \Sigma v^i_{Xj} \frac{d \ln q_j}{dT},$$
$$\frac{d \ln p^i_K}{dT} = \Sigma v^i_{Kk} \frac{d \ln p^i_{Kk}}{dT},$$
$$\frac{d \ln p^i_L}{dT} = \Sigma v^i_{Ll} \frac{d \ln p^i_{Ll}}{dT}, \qquad (i = 1, 2, \ldots, n).$$

We refer to these expressions $\{p^i_X, p^i_K, p^i_L\}$ as the *Divisia price indexes of sectoral intermediate input, capital input, and labor input.*

We can define rates of technical change for all $n$ sectors as the negative of rates of growth of the prices of sectoral output with respect to

3. The price function was introduced by Samuelson (1953).

time, holding the prices of intermediate input, capital input, and labor input constant:

$$v^i_T = -\frac{\partial \ln P^i}{\partial T}(p^i_X, p^i_K, p^i_L, T), \quad (i = 1, 2, \ldots, n).$$

We can express the rate of technical change for each sector as a weighted average of rates of growth of prices of input into the sector, less the rate of growth of the price of sectoral output, where the weights are given by the corresponding value shares:

$$\frac{d \ln q_i}{dT} = v^i_X \frac{d \ln p^i_X}{dT} + v^i_K \frac{d \ln p^i_K}{dT} + v^i_L \frac{d \ln p^i_L}{dT} - v^i_T, \quad (i = 1, 2, \ldots, n).$$

We refer to these expressions $\{v^i_T\}$ as the *Divisia price indexes of sectoral technical change.*

If sectoral output is a function of an aggregate for sectoral input, the price of sectoral output can be expressed as a function of the price of input, say $p^i_W$:

$$q_i = \frac{p^i_W(p^i_X, p^i_K, p^i_L)}{A_i(T)}, \quad (i = 1, 2, \ldots, n).$$

The rate of sectoral technical change depends only on time and the price of sectoral input depends only on the prices of intermediate, capital, and labor input. The existence of a quantity aggregate for sectoral input is equivalent to the existence of a price aggregate for sectoral input, and either is equivalent to Hicks neutrality of technical change. It is important to emphasize that we do not employ the assumption of Hicks neutrality, since we do not require the existence of quantity or price indexes for sectoral input in constructing our indexes of sectoral productivity.

The product of Divisia price and quantity indexes for an aggregate is equal to the sum of the values of its components. For example, the product of the price and quantity indexes for intermediate input into a sector is equal to the sum of the values of intermediate inputs that make up the aggregate. Second, Divisia indexes have the *reproductive property* that a Divisia index of Divisia indexes is also a Divisia index of the components of each index. For example, if sectoral input is composed of three subaggregates—intermediate input, capital input, and labor input—the Divisia index of sectoral input can be defined in two equivalent ways. First, sectoral input is a Divisia index of Divisia indexes of sectoral intermediate, capital, and labor input. Alternatively, sectoral input is a Divisia index of the individual intermediate, capital, and labor inputs into the sector. Divisia price indexes also have the reproductive property.

### 1.1.3 Index Numbers

While Divisia price and quantity indexes are useful in defining sectoral output, sectoral intermediate, capital, and labor input, and sectoral productivity in terms of data on quantities and prices, we find it essential to extend our methodology to incorporate price and quantity data at discrete points of time.[4] For this purpose we consider specific forms of the sectoral production functions $\{F^i\}$:

$$\begin{aligned} Z_i = \exp [&\alpha^i_0 + \alpha^i_X \ln X_i + \alpha^i_K \ln K_i + \alpha^i_L \ln L_i \\ &+ \alpha^i_T \cdot T + \frac{1}{2} \beta^i_{XX} (\ln X_i)^2 \\ &+ \beta^i_{XK} \ln X_i \ln K_i + \beta^i_{XL} \ln X_i \ln L_i \\ &+ \beta^i_{XT} \ln X_i \cdot T + \frac{1}{2} \beta^i_{KK} (\ln K_i)^2 \\ &+ \beta^i_{KL} \ln K_i \ln L_i + \beta^i_{KT} \ln K_i \cdot T \\ &+ \frac{1}{2} \beta^i_{LL} (\ln L_i)^2 + \beta^i_{LT} \ln L_i \cdot T \\ &+ \frac{1}{2} \beta^i_{TT} \cdot T^2], \qquad (i = 1, 2, \ldots, n). \end{aligned}$$

For these production functions, sectoral outputs are transcendental or, more specifically, exponential functions of the logarithms of inputs. We refer to these forms as *transcendental logarithmic production functions* or, more simply, translog production functions.[5]

The translog production function for an industrial sector is characterized by constant returns to scale if and only if the parameters for that sector satisfy the conditions

$$\begin{aligned} &\alpha^i_X + \alpha^i_K + \alpha^i_L = 1, \\ &\beta^i_{XX} + \beta^i_{XK} + \beta^i_{XL} = 0, \\ &\beta^i_{XK} + \beta^i_{KK} + \beta^i_{KL} = 0, \\ &\beta^i_{XL} + \beta^i_{KL} + \beta^i_{LL} = 0, \\ &\beta^i_{XT} + \beta^i_{KT} + \beta^i_{LT} = 0, \qquad (i = 1, 2, \ldots, n). \end{aligned}$$

For each sector the value shares of intermediate, capital, and labor input can be expressed as

4. Nelson (1973) and Usher (1974) have pointed out the need to define indexes appropriate for discrete points of time.

5. The translog production function was introduced by Christensen, Jorgenson, and Lau (1971, 1973). The treatment of technical change outlined below is due to Diewert (1977) and to Jorgenson and Lau (1977).

$$v^i_X = \alpha^i_X + \beta^i_{XX} \ln X_i + \beta^i_{XK} \ln K_i + \beta^i_{XL} \ln L_i$$
$$+ \beta^i_{XT} \cdot T,$$
$$v^i_K = \alpha^i_K + \beta^i_{XK} \ln X_i + \beta^i_{KK} \ln K_i + \beta^i_{KL} \ln L_i$$
$$+ \beta^i_{KT} \cdot T,$$
$$v^i_L = \alpha^i_L + \beta^i_{XL} \ln X_i + \beta^i_{KL} \ln K_i + \beta^i_{LL} \ln L_i$$
$$+ \beta^i_{LT} \cdot T, \qquad (i = 1, 2, \ldots, n).$$

The rate of sectoral technical change can be expressed as

$$v^i_T = \alpha^i_T + \beta^i_{XT} \ln X_i + \beta^i_{KT} \ln K_i$$
$$+ \beta^i_{LT} \ln L_i + \beta^i_{TT} \cdot T, \qquad (i = 1, 2, \ldots, n).$$

If we consider data for an industrial sector at any two discrete points of time, say $T$ and $T - 1$, the average rate of sectoral technical change can be expressed as the difference between successive logarithms of sectoral output less a weighted average of the differences between successive logarithms of sectoral intermediate, capital, and labor input with weights given by average value shares:

$$\ln Z_i (T) - \ln Z_i (T - 1) = \bar{v}^i_X[\ln X_i (T)$$
$$- \ln X_i (T - 1)] + \bar{v}^i_K[\ln K_i(T) - \ln K_i(T - 1)]$$
$$+ \bar{v}^i_L[\ln L_i (T) - \ln L_i (T - 1)]$$
$$+ \bar{v}^i_T, \qquad (i = 1, 2, \ldots, n),$$

where

$$\bar{v}^i_X = \frac{1}{2} [v^i_X(T) + v^i_X(T - 1)],$$

$$\bar{v}^i_K = \frac{1}{2} [v^i_K(T) + v^i_K(T - 1)],$$

$$\bar{v}^i_L = \frac{1}{2} [v^i_L(T) + v^i_L(T - 1)],$$

$$\bar{v}^i_T = \frac{1}{2} [v^i_T(T) + v^i_T(T - 1)], \qquad (i = 1, 2, \ldots, n).$$

We refer to these expressions for the average rate of sectoral technical change $\{\bar{v}^i_T\}$ as the *translog indexes of the sectoral rates of technical change.*

Similarly, we can consider specific forms for sectoral intermediate, capital, and labor input as functions of individual intermediate, capital, and labor inputs into each industrial sector. For example, sectoral intermediate input can be expressed as a translog function of individual intermediate inputs:

$$X_i = \exp [\alpha^i_1 \ln X_{1i} + \alpha^i_2 \ln X_{2i} + \ldots + \alpha^i_n \ln X_{ni}$$
$$+ \frac{1}{2} \beta^i_{11} (\ln X_{1i})^2$$
$$+ \beta^i_{12} \ln X_{1i} \ln X_{2i} + \ldots$$
$$+ \frac{1}{2} \beta^i_{nn} (\ln X_{ni})^2], \qquad (i = 1, 2, \ldots, n).$$

Intermediate input for an industrial sector is characterized by constant returns to scale if and only if the parameters for that sector satisfy the conditions

$$\alpha^i_1 + \alpha^i_2 + \ldots + \alpha^i_n = 1,$$
$$\beta^i_{11} + \beta^i_{12} + \ldots + \beta^i_{1n} = 0,$$
$$\cdots\cdots\cdots$$
$$\beta^i_{1n} + \beta^i_{2n} + \ldots + \beta^i_{nn} = 0, \qquad (i = 1, 2, \ldots, n).$$

For each sector the value shares of individual intermediate inputs $\{X_{ji}\}$ can be expressed as

$$v^i_{Xj} = \alpha^i_j + \beta^i_{1j} \ln X_{1i} + \ldots$$
$$+ \beta^i_{jn} \ln X_{ni}, \qquad (i = 1, 2, \ldots, n).$$

Considering data on intermediate inputs into an industrial sector at any two discrete points of time, we can express the difference between successive logarithms of sectoral intermediate input as a weighted average of differences between successive logarithms of individual intermediate inputs into the sector with weights given by average value shares:

$$\ln X_i (T) - \ln X_i (T-1) = \Sigma \bar{v}^i_{Xj} [\ln X_{ji} (T)$$
$$- \ln X_{ji} (T-1)], \qquad (i = 1, 2, \ldots, n),$$

where

$$\bar{v}^i_{Xj} = \frac{1}{2} [v^i_{Xj} (T) + v^i_{Xj} (T-1)], \ (i = 1, 2, \ldots, n).$$

Similarly, if capital and labor input into each industrial sector are translog functions of their components, we can express the difference between successive logarithms of sectoral capital and labor input in the form

$$\ln K_i (T) - \ln K_i (T-1) = \Sigma \bar{v}^i_{Kk} [\ln K_{ki} (T)$$
$$- \ln K_{ki} (T-1)],$$

$$\ln L_i(T) - \ln L_i(T-1) = \Sigma \bar{v}^i_{Ll} [\ln L_{li}(T) - \ln L_{li}(T-1)], \qquad (i = 1, 2, \ldots, n),$$

where

$$\bar{v}^i_{Kk} = \frac{1}{2} [v^i_{Kk}(T) + v^i_{Kk}(T-1)], \qquad (i = 1, 2, \ldots, n; k = 1, 2, \ldots, p),$$

$$\bar{v}^i_{Ll} = \frac{1}{2} [v^i_{Ll}(T) + v^i_{Ll}(T-1)], \qquad (i = 1, 2, \ldots, n; l = 1, 2, \ldots, q).$$

We refer to these expressions for sectoral intermediate, capital, and labor input $\{X_i, K_i, L_i\}$ as *translog indexes of sectoral intermediate, capital, and labor input.*[6]

The product of price and quantity indexes of sectoral intermediate, capital, and labor input must be equal to the sum of the values of the individual intermediate, capital, and labor inputs into each sector. For example, we can define the price index corresponding to the translog quantity index of sectoral intermediate input as the ratio of the value of intermediate input into the sector to the translog quantity index. Price indexes corresponding to the translog quantity indexes of sectoral capital and labor input can be defined in the same way. The resulting price indexes of sectoral intermediate, capital, and labor input do not have the form of translog price indexes, but they can be determined from data on prices and quantities at any two discrete points of time. Translog quantity indexes do not have the reproductive property we have described above for Divisia indexes; the translog index for an aggregate depends on the structure of the subaggregates on which it is defined.[7]

## 1.2 Labor Input

### 1.2.1 Introduction

In describing and analyzing postwar patterns of productivity growth in the U.S. economy, our initial objective is to construct measures of

6. The quantity indexes were introduced by Fisher (1922) and have been discussed by Tornqvist (1936), Theil (1965), and Kloek (1966). These indexes were first derived from the translog production function by Diewert (1976). The corresponding index of technical change was introduced by Christensen and Jorgenson (1970). The translog index of technical change was first derived from the translog production function by Diewert (1977) and Jorgenson and Lau (1977). Earlier, Diewert (1976) had interpreted the ratio of translog indexes of output and input as an index of technical change under the assumption of Hicks neutrality.

7. This corrects an error in Christensen and Jorgenson (1973*a*), p. 261.

labor input in current and constant prices for each industrial sector.[8] Measures of labor input in constant prices are index numbers constructed from data on hours worked and compensation per hour for each sector. Our data on hours worked and labor compensation for each industry are cross-classified by sex, age, education, employment status, and occupation of workers. To construct measures of labor input that are consistent with the U.S. national income and product accounts we have controlled these data to industry totals based on establishment surveys. To disaggregate labor input by industrial and demographic characteristics of the work force we have exploited the detail on employment, hours worked, and compensation available from household surveys. To achieve consistency between establishment and household survey data we have used the household survey results to distribute industry totals based on establishment surveys.

We have disaggregated the labor input of all employed persons into cells cross-classified by the two sexes, eight age groups, five education groups, two employment classes, ten occupational groups, and fifty-one industries listed in table 1.1. This breakdown of labor input characteristics is based on the groupings employed by the Bureau of Census in reporting data from household surveys. The census data provide the only source of consistent time series on the work force cross-classified by industrial and demographic characteristics. With few exceptions, data on labor input for the fifty-one industry groups listed in table 1.1 are also available from establishment surveys employed in construction of the U.S. national income and product accounts. Neither household nor establishment surveys provide data on hours worked and labor compensation for the 81,600 cells of a matrix cross-classified by the characteristics given in table 1.1.[9] Moreover, we require four such matrices, one for each of four components of labor input: employment, hours, weeks, and labor compensation. While the complete cross-classifications are not available directly, marginal totals cross-classified by two, three, and sometimes four characteristics of labor input are available for each year from 1947 to 1973.

8. The initial design of our approach to the measurement of labor input, the collection of data, and much of the required estimation were carried out in collaboration with Peter Chinloy. The results of his measurement and analysis of labor input for the U.S. economy at the aggregate level are reported in his doctoral dissertation. See Chinloy (1974).

9. The 81,600 cell total is the product of the number of characteristic divisions within each industrial and demographic dimension: (51) • (2) • (2) • (8) • (5) • (10). A substantial number of these cells will have zero entries; an example is the number of "fourteen- or fifteen-year old" laborers with "four or more years of college" in each of the 2040 cells cross-classified by industry, occupation, sex, and employment class. In implementing the multiproportional matrix model discussed below we need not identify the empty cells prior to estimation; these cells are treated symmetrically with those for which entries are different from zero.

**Table 1.1 Characteristics of Labor Input**

Sex
(1) Male
(2) Female

Age
(1) 14–15 years
(2) 16–17 years
(3) 18–24 years
(4) 25–34 years
(5) 35–44 years
(6) 45–54 years
(7) 55–64 years
(8) 65 years and over

Education
(1) 1–8 years grade school
(2) 1–3 years high school
(3) 4 years high school
(4) 1–3 years college
(5) 4 or more years college

Employment Class:
(1) Wage and salary worker
(2) Self-employed/unpaid family worker

Occupation:
(1) Professional, technical, and kindred workers
(2) Farmers and farm managers
(3) Managers and administrators, except farm
(4) Clerical workers
(5) Sales workers
(6) Craftsmen and kindred workers
(7) Operatives
(8) Service workers, including private household
(9) Farm laborers
(10) Laborers, except farm

Industry:
(1) Agricultural production
(2) Agricultural services, horticultural services, forestry, and fisheries
(3) Metal mining
(4) Coal mining
(5) Crude petroleum and natural gas extractions
(6) Nonmetallic mining and quarrying, except fuel
(7) Construction
(8) Food and kindred products
(9) Tobacco manufactures
(10) Textile mill products
(11) Apparel and other fabricated textile products
(12) Paper and allied products
(13) Printing, publishing, and allied industries
(14) Chemicals and allied products

**Table 1.1** (continued)

| | |
|---|---|
| (15) | Petroleum and coal products |
| (16) | Rubber and miscellaneous plastic products |
| (17) | Leather and leather products |
| (18) | Lumber and wood products, except furniture |
| (19) | Furniture and fixtures |
| (20) | Stone, clay, and glass products |
| (21) | Primary metal industries |
| (22) | Fabricated metal industries |
| (23) | Machinery, except electrical |
| (24) | Electrical machinery, equipment, and supplies |
| (25) | Transportation equipment, except motor vehicles, and ordnance |
| (26) | Motor vehicles and motor vehicle equipment |
| (27) | Professional photographic equipment, and watches |
| (28) | Miscellaneous manufacturing industries |
| (29) | Railroads and railway express service |
| (30) | Street railway and bus lines and taxicab service |
| (31) | Trucking service and warehousing and storage |
| (32) | Water transportation |
| (33) | Air transportation |
| (34) | Pipelines, except natural gas |
| (35) | Services incidental to transportation |
| (36) | Telephone, telegraph, and miscellaneous communication services |
| (37) | Radio broadcasting and television |
| (38) | Electric utilities |
| (39) | Gas utilities |
| (40) | Water supply, sanitary services, and other utilities |
| (41) | Wholesale trade |
| (42) | Retail trade |
| (43) | Finance, insurance, and real estate |
| (44) | Services |
| (45) | Private households |
| (46) | Nonprofit institutions |
| (47) | Federal public administration |
| (48) | Federal government enterprises |
| (49) | Educational services, government (state and local) |
| (50) | State and local public administration |
| (51) | State and local government enterprises |

Our first task is to construct matrices cross-classified by the industrial and demographic characteristics listed in table 1.1 for all four components of labor input for each year of the period 1947–73. To accomplish this goal we introduce a multiproportional matrix model, generalizing the RAS method introduced by Stone (1962). The statistical principles underlying this model are a straightforward extension of those that underlie the biproportional matrix model of Bacharach (1965). We present the multiproportional matrix model in section 1.2.2. We have employed all the available published information on marginal totals for each component of labor input available from the Census of Population and the Current Population Survey. The sources for the data on employment, hours, weeks, and labor compensation and the procedures we have adopted in constructing the matrices that underlie our index numbers for labor input are outlined in the following sections. In section 1.2.3 we describe our estimates of hours worked per year; our estimates of labor compensation per hour worked are described in section 1.2.4.

The desirability of disaggregating labor input by industrial and demographic characteristics of the work force has been widely recognized, for example by Denison (1962), Griliches (1960), Jorgenson and Griliches (1967), Kendrick (1961), and others. Kendrick has developed measures of labor input disaggregated by industry for much of the postwar period, but his measures do not incorporate a cross-classification of labor input by age, sex, education, or other demographic characteristics of the work force. Denison has developed measures of labor input for the U.S. economy as a whole based on data disaggregated by sex, age, education, and employment status, but not by occupation or industry.[10]

Data on labor input cross-classified by characteristics such as employment class, occupation, and industry are required in studies of labor demand; data cross-classified by characteristics such as sex, age, and education are required in studies of labor supply. In the absence of data disaggregated by both industrial and demographic characteristics, measures of labor input that fail to reflect differences in productivity among workers remain in common use. A recent illustration is provided by a study of the growth of labor input during the postwar period by the Bureau of Labor Statistics (1973*b*). The study provides data on hours worked for broadly defined age-sex groups and five major industrial groups. No attempt is made to construct measures of labor input that reflect differences in productivity among workers:

> All manhours published in this bulletin are treated as homogeneous units. In other words, changes in the quality of labor, as reflected in shifts toward high skilled workers and increased wage rates, are not reflected in the estimates.[11]

10. Kendrick purposely avoids disaggregating the employed population by demographic characteristics. Any difference in the productivity of an hour's work by laborers of differing personal characteristics should, in Kendrick's view, be captured not in a measure of factor input but in an index of productivity change. By contrast, Denison posits that disaggregation by personal characteristics is essential in measuring labor input. In his view, shifting composition by industrial and occupational characteristics does not reflect changes in the level of labor input but should be included in the measure of productivity change.

11. U.S. Bureau of Labor Statistics (1973*b*), p. 32.

We present indexes of labor input for the fifty-one industry groups included in our study in section 1.2.5. Our data base can be used to generate indexes of labor input cross-classified by each of the characteristics we have employed in compiling data on hours worked and compensation per hour.

### 1.2.2 Multiproportional Matrix Model

For each year in the period 1947–73 we require matrices of data on hours worked and labor compensation per hour, cross-classified by the demographic and industrial characteristics of labor input listed in table 1.1. This cross-classification involves a total of 81,600 entries for each matrix for each year. Data on the components of labor input—employment, hours per week, weeks per year, and labor compensation—are not available in published form for such a detailed cross-classification. However, considerable detail is available for individual years on the basis of two-way, three-way, and even four-way cross-classifications. Data from the decennial Census of Population is more detailed than data from the annual Current Population Survey. Our objective is to exhaust the detail available from both sources in constructing matrices for each component of labor input for each year.

In constructing matrices for employment, hours per week, weeks per year, and labor compensation we employ the published cross-classifications as control totals. The problem that remains is to generate estimates of each component of labor input for all 81,600 cells of the cross-classification presented in table 1.1 for each year. For this purpose we have developed a multiproportional matrix model, generalizing the RAS method introduced by Stone (1962) and formalized by Bacharach (1965) as the biproportional matrix model. To illustrate the multiproportional matrix model we find it useful to consider the biproportional matrix model as an example. Consider two nonnegative matrices, say $A$ and $B$. The elements of the first matrix, say $\{a_{ij}\}$, are known. The problem is to estimate the unknown elements, say $\{b_{ij}\}$ of the second matrix, where only the row and column sums $\{u_i\}$ and $\{v_j\}$,

$$\sum_{j=1}^{n} b_{ij} = u_i, \qquad (i = 1, 2, \ldots, m),$$

$$\sum_{i=1}^{m} b_{ij} = v_j, \qquad (j = 1, 2, \ldots, n),$$

are known.

To specify the problem of estimating the unknown elements $\{b_{ij}\}$ more precisely, we introduce the assumption that the matrix $B$ is *biproportional* to the matrix $A$, that is,

$$b_{ij} = r_i s_j a_{ij}, \qquad (i = 1, 2, \ldots, m; j = 1, 2, \ldots, n),$$

where $r_i$ is a factor associated with the $i$th row of $A$ and $s_j$ is a factor associated with the $j$th column of $A$. The problem of estimating the unknown elements of the matrix $B$ reduces to the problem of choosing row and column factors $\{r_i, s_j\}$ so that the row and column sums are equal to the known row and column sums $\{u_i, v_j\}$ and the elements of $B$ are nonnegative. To state the problem more formally we can introduce the diagonal matrix $\hat{r}$ with diagonal elements $\{r_i\}$ and the diagonal matrix $\hat{s}$ with diagonal elements $\{s_j\}$. We can represent sequences of such matrices by $\{\hat{r}^t, \hat{s}^t\}$. The set of matrices $B$ that are biproportional to the matrix $A$ is defined by the conditions

$$B = \lim_{t \to \infty} \hat{r}^t A \hat{s}^t,$$

$$B \geq 0,$$

$$B\iota = \boldsymbol{u},$$

$$\iota' B = \boldsymbol{v},$$

where $\iota$ is a vector of ones, $\boldsymbol{u}$ is a vector with elements $\{u_i\}$, and $\boldsymbol{v}$ is a vector with elements $\{v_j\}$.

The matrices $B$ that are biproportional to a given matrix $A$ can be written in the "RAS" form

$$B = \hat{r} A \hat{s},$$

or as the limit of such matrices. Bacharach shows that for any matrix $A$ such that every row and every column has at least one positive element, and for any vectors $\boldsymbol{u}$ and $\boldsymbol{v}$ with all elements positive and

$$\Sigma u_i = \Sigma v_j,$$

there exists a unique nonnegative matrix $B$ that is biproportional to nonnegative matrix $A$.[12] The method for constructing the matrix $B$ proposed by Stone (1962) and others involves an iterative process. The first iteration requires two steps:

1. Multiply the $i$th row by a scalar, say $r^1{}_i$, such that the row sum is equal to the given total $u_i$.
2. Multiply the $j$th column by a scalar, say $s^1{}_j$, such that the column sum is equal to the given total $v_j$.

The result of this process is a new, nonnegative matrix, say $A^1$, that serves as the starting point of the next iteration. Successive iterations of the process define a sequence of matrices $\{A^t\}$ defined by

12. Bacharach (1965), pp. 302–8.

$$A^t = \hat{r}^t A^{t-1} \hat{s}^t, \qquad (t = 1, 2, \ldots),$$

where

$$A^0 = A.$$

Bacharach shows that the process converges to the unique biproportional matrix $B$.[13]

We next consider the multiproportional matrix model. In defining this model we find it useful to rewrite the nonnegative matrix $A$, where

$$A = [a_1, a_2 \ldots a_n],$$

and $a_j$ is the $j$th column of $A$, as a column vector, say $\boldsymbol{a}$, where

$$\boldsymbol{a} = \begin{bmatrix} a_1 \\ a_2 \\ \cdot \\ \cdot \\ \cdot \\ a_n \end{bmatrix}.$$

Next, we consider any partition of the elements of $\boldsymbol{a}$, that is, any set of subsets of the elements of $\boldsymbol{a}$ such that each element is assigned to one and only one subset. We restrict consideration to partitions of the elements of $\boldsymbol{a}$ such that each subset contains at least one positive element. As before, the elements of the matrix $A$ or the column vector $\boldsymbol{a}$ are known. The problem is to estimate the unknown elements of a matrix $B$, where

$$B = [b_1, b_2 \ldots b_n],$$

and $b_j$ is the $j$th column of $B$, or the column vector $\boldsymbol{b}$:

$$\boldsymbol{b} = \begin{bmatrix} b_1 \\ b_2 \\ \cdot \\ \cdot \\ \cdot \\ b_n \end{bmatrix}.$$

We consider a partition of the vector $\boldsymbol{b}$ corresponding to any given partition of the vector $\boldsymbol{a}$, denoting the sum of all elements in the $i$th subset of the $j$th partition of $\boldsymbol{b}$ by $u^j_i$, where all such sums are positive and the sum over all subsets is the same for all partitions. We say that the vector $\boldsymbol{b}$ is *multiproportional* to the vector $\boldsymbol{a}$ if the following conditions are satisfied:

13. Ibid., p. 304.

1. There are factors $\{r^j_i\}$ such that each element of $\boldsymbol{b}$ can be represented either as the product of such factors, one for each partition, and the corresponding element of $\boldsymbol{a}$ or as the limit of a sequence of products of this type.
2. The vector $\boldsymbol{b}$ is nonnegative.
3. The sum of elements of $\boldsymbol{b}$ in the $i$th subset of the $j$th partition is equal to $u^j_i$.

There exists a unique nonnegative vector $\boldsymbol{b}$ that is multiproportional to a nonnegative vector $\boldsymbol{a}$.

To construct the vector $\boldsymbol{b}$ that is multiproportional to a vector $\boldsymbol{a}$, we employ an iterative process. The first iteration requires as many steps as there are partitions of the vector $\boldsymbol{a}$. At the $j$th step we multiply the elements in the $i$th subset of the $j$th partition by a scalar, say $r^{j1}_i$, such that the sum of elements in the subset is equal to the given total $u^j_i$. The result of this process is a new, nonnegative vector, say $\boldsymbol{a}^1$, that serves as the starting point of the next iteration. Successive iterations of the process define a sequence of vectors $\{\boldsymbol{a}^t\}$ such that each element is the product of the scalars $\{r^{jt}_i\}$ and the corresponding element from the preceding iteration, where

$$\boldsymbol{a}^0 = \boldsymbol{a}.$$

This process converges to the unique multiproportional vector $\boldsymbol{b}$.

As an illustration of the multiproportional matrix model, consider the case where one has available information separately classified by each of two characteristics and wishes to construct a matrix cross-classified by these characteristics. Both marginal distributions can be used as input into the multiproportional matrix model, following the iterative procedure outlined above. If a three-way cross-classification is the objective and the data set includes all three possible two-way cross-classifications, the multiproportional matrix model can be applied in four ways. Any pair of two-way cross-classifications can be employed or all three can be used simultaneously. Fortunately, the appropriate choice can be made on elementary grounds. In estimating the elements of the multiproportional matrix, the number of degrees of freedom can be reduced to a minimum by using as much overlapping marginal information as is available. In this example, all three two-way cross-classifications would be employed in the model as marginal distributions.

### 1.2.3 Annual Hours Worked

*Introduction*

The task of developing measures of labor input cross-classified by sex, age, education, employment status, and occupation for each industry can be divided between compiling data on annual hours worked and compiling data on labor compensation. In this section we present our methodology and data sources for constructing annual data on hours worked; we discuss the development of data on labor compensation in the following section. Our first step in measuring annual hours worked is to construct employment matrices for the civilian work force for each postwar year, cross-classified by sex, age, education, employment class, occupation, and industry of employment. Marginal totals for employment are based on the last three decennial Censuses of Population and the postwar Current Population Survey. We combine data from these sources by means of the multiproportional matrix model presented in the preceding section. The resulting employment matrices are adjusted to employment totals by industry from the U.S. national income and product accounts.

The second step in measuring annual hours worked is to incorporate differences in hours worked by different groups of workers. Since establishment-based surveys provide data on hours paid rather than hours worked, hours paid have often been substituted for hours worked in measuring labor input. The latter is clearly more appropriate as a measure of labor input. The growing importance of hours that are paid but not worked due to vacations, illness, personal leaves, and holidays leads to an upward bias in the growth of hours worked if data on hours paid are substituted for data on hours worked. To avoid the deficiencies of establishment-based data on hours paid we employ data on hours worked from household surveys reported in the decennial census and the Current Population Survey. We employ the multiproportional matrix model in constructing matrices of hours worked per week, cross-classified by sex, age, employment class, occupation, and industry for each year. The resulting hours-worked matrices are adjusted to industry totals from the national accounts. We define annual hours worked for each category of labor input as the product of employment, hours worked per week, and the number of weeks in the calendar year, fifty-two.

*Employment*

Our first step in constructing employment matrices for the civilian work force for each postwar year is to assign each worker to one of 81,600 cells, cross-classified by sex, age, education, employment class, occupation, and industry of employment. Information for the years of the decennial Census of Population—1950, 1960, and 1970—is considerably more detailed than information available for other years from the Current Population Survey. We employed two-way, three-way, and four-way cross-classifications of employment from the census in generating the full six-way cross-classification for each census year. The value of employment for each cell in the detailed cross-classification was initialized at unity; all available marginal totals from each Census of

Population were used in the multiproportional matrix model to control the distribution of employment among cells for the corresponding year. We then ranked intermediate years by the detail available for marginal totals in each year. We initialized the employment matrix for each intermediate year by a weighted average of employment matrices from the nearest years for which an employment matrix was already available, beginning with a weighted average of matrices based on the decennial censuses. All available marginal totals available for each year were incorporated by means of the multiproportional matrix model. For the years 1947, 1948, 1949, 1971, 1972, and 1973 this process was initialized with the nearest year for which an employment matrix was available.

The incorporation of Alaska and Hawaii into U.S. census data in 1960 and the redefinition of census labor force concepts[14] beginning with the 1967 household survey necessitated special approaches to the labor input data for these years. The resolution of the discontinuity between 1959 and 1960 is straightforward. We have constructed two employment matrices for 1960—one defined on a basis comparable with earlier years, the other to later years. Since the 1960 census was the first survey to incorporate data for Alaska and Hawaii, we create a separate employment matrix for the forty-ninth and fiftieth states by means of the multiproportional matrix model. The matrix for the two states is then subtracted from the matrix for all fifty states to create a second 1960 matrix that is comparable with 1959 and earlier years.

Fortunately, most of the definitional changes introduced by the Bureau of the Census in January 1967 affect the distinction between the unemployed and those who are not in the labor force and did not affect data on the employed labor force. Three changes did affect the employment data. First, employed persons who are not at work during the survey week and are looking for another job had their classification changed from unemployed to employed:

> Up to now (January 1967) the small group of persons absent from their jobs the entire survey week because of vacations, illness, strikes,

14. Most of the definitional changes introduced by the Census Bureau in January 1967 affect the distinction between the unemployed and those who are not in the labor force. See Stein (1967). These changes do not influence this study. However, changes in the interviewers' questioning policy and the bureau's classificatory criteria do have an impact. Beginning in January 1967, (i) those persons, previously classified as unemployed, who were absent from their jobs during the entire survey week because of vacations, strikes, etc., but were looking for other jobs were now classified as employed; (ii) former proprietors who later incorporated their businesses were now assigned to the wage and salary class rather than the self-employed category; and (iii) all fourteen- and fifteen-year-old laborers were no longer considered part of the labor force.

> bad weather, etc., who were looking for other jobs was classified as unemployed. Starting in January 1967, such persons are classified as employed—that is, among others "with a job but not at work."[15]

This definitional change shifted approximately 80,000 persons[16] from the unemployed to the employed category.

We ultimately control our employment data to totals based on establishment surveys. Since these totals include all workers who received pay during the survey period, whether or not they actually worked during the period, the establishment survey classifies workers receiving pay from one job, though physically absent and looking for another job, as employed. The control totals for our employment data are unaffected by the first census redefinition. Since there is no evidence to suggest that the industrial and demographic characteristics of the 80,000 persons reclassified from unemployed to employed are different from the characteristics of the employed population, we made no adjustments in the distribution of workers in our employment matrices based on household surveys.

The second census redefinition involved a more accurate classification of employed persons between wage and salary workers and self-employed and unpaid family workers. Prior to January 1967 a person was simply asked in which of the two classes he or she belonged. By the early sixties it had become clear that some proprietors who had incorporated their businesses were still defining themselves as part of the self-employed when, in actuality, they should be classified as employees of a corporate business. After January 1967, whenever a census-taker received a "self-employed" response, an additional question was asked to determine whether the "proprietor's" business was incorporated. The respondent was then properly classified into one of the two employment classes. The Census Bureau estimated that this question accounted for a shift of approximately 750,000 workers[17] from the self-employed to the wage and salary class.

To provide a basis for constructing continuous time series, the Census Bureau conducted a separate survey of 17,500 households, the Monthly Labor Survey, during 1966. This survey was based on the new questionnaire which was to become effective in January 1967. Paralleling this was the traditional Current Population Survey of 35,000 households. We could have treated this shift of 750,000 laborers in the same manner as the introduction of Alaska and Hawaii. We could have constructed a second 1966 matrix based on the Monthly Labor Survey. This matrix would be defined in terms consistent with 1967 and all later years.

15. Stein (1967), p. 7.
16. Ibid., p. 10.
17. Ibid.

However, unlike the addition of new states at a point in time, which leaves all labor matrices preceding the date of statehood unaffected, the reallocation of the corporate self-employed affects labor matrices in all years prior to 1967. Consequently, we find it essential to adjust all pre-1967 household matrices for the corporate self-employed.

The Bureau of Economic Analysis used the two 1966 census surveys to estimate the number of workers misclassified as self-employed in each industry in 1966. The Bureau then linearly extrapolated each industry's corporate self-employed back to 1948, assuming that the corporate self-employed were one-third the 1966 total in 1958 and zero in 1948. All the post-1947 employment totals reported in the national accounts were adjusted to reflect this reclassification. Although our employment matrices are controlled to totals from the Bureau of Economic Analysis, we require estimates of the demographic characteristics of the corporate self-employed. These workers are more likely to share the demographic characteristics of the self-employed than those of wage and salary workers.

For each industry and each year from 1948 to 1966 we distributed the corporate self-employed by sex, age, education, and occupation characteristics by allocating totals from the Bureau of Economic Analysis in proportion to the distribution of self-employed and unpaid family workers from the household survey.[18] We then subtracted this matrix for each industry and each year from the corresponding household employment matrix for self-employed workers and added it to the employment matrix for wage and salary workers. This procedure not only accounts for the definitional shifts occurring in 1967 but also corrects misallocations affecting the measure of labor input in each year from 1948 to 1966.

The final and most perplexing change introduced in 1967 involved the decision to drop all employed fourteen- and fifteen-year-olds from the census's definition of the labor force. While the Department of Commerce no longer provides data on these young workers cross-classified by the demographic characteristics previously reported, limited demographic data on employed fourteen- and fifteen-year-olds is still collected by the census bureau and reported separately from the usual labor force data. This information was used together with employment matrices representing those sixteen years old or over to construct a complete 1947–73 series for all employed persons fourteen years of age and older.

While census data based on household surveys provide the best source of data on labor input cross-classified by industrial and demographic

18. Results based on the Current Population Survey were used to initialize the multiproportional matrix model for 1966 and earlier years.

characteristics, industry totals must be reconciled with data based on establishment surveys. First, census reports suffer from a slight undercount. Part of the undercount can be attributed to the bureau's decision to classify a multiple job holder only in the industry where he works the most hours. A valid measure of annual hours worked requires a count of jobs held in the economy rather than a count of employed persons. This necessitates counting each laborer holding multiple jobs as employed in each industry in which he works no matter how insignificant the number of hours in his secondary jobs. Establishment-based surveys meet this requirement. Second, industry totals from establishment surveys include those employed workers who are less than fourteen years old. Since their contribution to output is captured in production measures, their labor input must be incorporated into a measure of total labor input.

Establishment surveys provide an enumeration of jobs rather than persons at work. The resulting employment data are based on annual average job counts from surveys of establishments. These data include workers who received pay but were not at work during the survey week, while household surveys count only those who were actually at work during the survey week. A worker who is absent from his job but paid during the survey week or employed at other times during the year is not absent for all fifty-two weeks of the calendar year. Exclusion of these workers would lead to a downward bias in annual labor input for the corresponding category of labor input. Using an establishment count of employees paid and later assigning to absent workers the average annual hours worked by workers with comparable demographic characteristics who received pay during the survey period provides a more attractive approach to measuring annual hours worked.

Both the Bureau of Economic Analysis and the Bureau of Labor Statistics publish annual establishment-based estimates of the number of employed persons by industry. Integration of our measure of labor input with the U.S. national income and product accounts requires that we use the Bureau of Economic Analysis estimates. These estimates are largely based on annual averages of the employment returns by individual establishments to state unemployment insurance bureaus. The payroll data account for nearly 80% of wages and salaries and almost 95% of wages and salaries in private industry. While the Bureau of Labor Statistics also bases its employment series to state unemployment insurance data, it controls its industry totals to the March returns rather than to annual averages. In addition, the Bureau of Labor Statistics data do not include agricultural and private household sectors, while data from the national income and product accounts include these sectors. After each year's census matrices had served as marginal inputs into the multiproportional matrix model, the resulting household matrices of employment were then adjusted to totals by industry from the national accounts. The result is a complete time series of matrices cross-classifying all employed persons by industrial and demographic characteristics for the period 1947–73.

*Hours*

Measures of labor input must incorporate differences in hours worked by different groups of workers. The Bureau of Labor Statistics publishes data on hours paid based on establishment surveys. Hours data are compiled only for production labor in manufacturing and nonsupervisory workers in nonmanufacturing, so that hours worked for supervisory, self-employed, and unpaid family workers are unavailable. A more important limitation in the series published by the Bureau of Labor Statistics is that hours data by industry are not cross-classified by demographic characteristics. To avoid the deficiencies of establishment-based hours data we use the hours data collected and published by the Bureau of the Census. The census reports only those hours that were actually *worked* during the survey week and thus automatically excludes vacations, holidays, illness, personal leave, and all other circumstances during which an employed person may be paid for hours he did not work.

The Census provides data on hours worked cross-classified by the demographic and industrial characteristics listed in table 1.1. An analysis of the hours-worked data published by the Bureau of the Census reveals that the total hours worked per week associated with individuals in each cell has a distribution that can be accurately represented by the lognormal distribution. We therefore assume that the hours worked by the individuals in each cell have a lognormal distribution with unknown location and dispersion parameters. Assigning each employed person to the appropriate cell cross-classified by sex, age, employment status, occupation, and industry[19] and imposing this lognormality assumption on the distribution of hours worked, we can estimate the two unknown parameters by the method of maximum likelihood.

The method of maximum likelihood cannot be applied directly to census data on hours worked, since the data are not presented as individual observations, but rather as empirical frequency distributions. For example, for a given set of labor input characteristics, the census presents the number of laborers who fall within each of the following discrete hour classes: 0 hours worked, 1–14, 15–26, 27–34, 35–40, 40, and 41 or more. Gjeddebaek (1949) has provided an adaptation of the method of maximum likelihood which is directly applicable to

19. Unfortunately, there are no available data covering the postwar period which classify hours worked by education.

data in frequency form.[20] The raw frequency data are interpreted as drawings from a multinomial model where the units within any given cell are divided into mutually exclusive groups corresponding to the census intervals. Using the lognormal distribution to describe the probabilities of observing individuals in each interval, the likelihood of observing any given empirical distribution of hours worked can be maximized.

While the multinomial model enables us to obtain estimates of mean hours worked for each demographic cell in each marginal distribution provided by the census, these averages will be biased upward unless they are adjusted for holders of multiple jobs. This bias arises because the census classifies a person holding more than one job as employed only in that industry in which he works the most hours. Furthermore, the census allocates to that industry the multiple job holder's total hours worked at all jobs regardless of the industry in which the hours were actually worked. This accounting framework incorrectly assigns the total number of hours to the primary job, while neglecting to assign the appropriate number of hours worked by multiple job holders to their secondary jobs.

The separate effects of the census's procedure of assigning employed persons and their hours worked solely to primary industries reinforce each other, leading to mean estimates that are biased upward. Consider two industries A and B which together employ three workers. The first works 5 hours in A, the second works 20 hours in A and 15 in industry B, and the third works 10 hours in B and 5 hours in A. The true mean hours worked in each industry are as follows:

$$\text{Industry A: } \frac{(5 + 20 + 5)}{3} = 10,$$

$$\text{Industry B: } \frac{(15 + 10)}{2} = 12.5.$$

Calculating these averages on the basis of raw data reported by the census would lead to the following estimates:

$$\text{Industry A: } \frac{(L_1 + L_2)}{2} = \frac{(5 + 35)}{2} = 20,$$

$$\text{Industry B: } \frac{(L_3)}{1} = 15.$$

Thus, failure to adjust for multiple job holders clearly leads to an upward bias in all industries where multiple job holders play a role.

20. Barger (1971) has applied Gjeddebaek's method to the estimation of mean earnings from data available in frequency form.

Using data on hours published in the *Special Labor Force Reports*, we subtract from each cell created directly from the census reports those hours that were worked in other industries and add these hours to the appropriate secondary industries. The multiproportional matrix model is then used to construct a matrix of average weekly hours worked by persons cross-classified by sex, age, employment class, occupation, and industry. We first construct matrices of hours worked for the years of the decennial Census of Population, initializing the matrix for each year with the corresponding employment matrix and incorporating all available marginal totals. For intermediate years the matrix is initialized by a matrix with entries equal to the product of the entries from the corresponding employment matrix and a weighted average of the entries from matrices of average hours worked from the nearest years for which an hours matrix was available.

The household survey data on employment and hours worked for the 1948–66 period are based on a set of definitions allocating the corporate self-employed to the class of self-employed and unpaid family workers. Applying the multinomial model to the frequency distributions of hours worked by the self-employed as reported in both the Current Population Survey and the Monthly Labor Survey for 1966, we determined that weekly hours worked in 1966 by the corporate self-employed are not statistically different from the weekly hours worked by all self-employed workers, but are different from the weekly hours worked by wage and salary workers. In most cases, the corporate self-employed worked more hours per week than their wage and salary counterparts. Using the demographic and industrial distribution of the corporate self-employed, as described above, and estimating average weekly hours worked by these workers from data on average weekly hours worked by self-employed workers with comparable demographic and industrial characteristics, we adjust each entry in our matrices of weekly hours for wage and salary workers for the years 1948 to 1966 to reflect the weekly hours worked by the corporate self-employed. No adjustment of the matrices on average weekly hours worked by self-employed workers is required.

Using data on annual totals of hours worked by industry, recently compiled and published by the Bureau of Economic Analysis, we control our estimates of annual hours worked within each industry to totals for the industry. Our first step is to convert BEA estimates of annual hours worked for each industry to weekly hours worked by dividing by the number of weeks in a calendar year, fifty-two. Controlling our weekly hours matrices to these totals and dividing by our employment matrices enumerating jobs, we obtain estimates of average weekly hours per job. It is important to emphasize that the corresponding frequency distributions of hours worked from the census household surveys include workers "with a job but not at work" as reporting zero hours worked in the survey week. These workers are included in our estimates of average hours worked, so that we obtain weekly hours worked per job for each category of worker. Consequently, we control our estimates of weekly hours worked per job for each industry to estimates of weekly hours worked per job from the Bureau of Economic Analysis data on hours worked and employment. The result is an annual series of matrices of average weekly hours *worked* per job, cross-classified by the demographic and industrial characteristics presented in table 1.1.

### 1.2.4 Labor Compensation

*Introduction*

The choice of an appropriate accounting framework for measuring the compensation of labor input is important for at least two reasons. First, labor compensation is required in order to weight hours worked in forming an index of labor input for each industry. Second, the total wage bill must reflect labor's share in total cost in the measurement of productivity. Our approach to the measurement of labor compensation is based on data for average compensation for the civilian work force from the last three decennial Censuses of Population. These data provide estimates of average compensation per person; our employment data provide estimates of the number of jobs. Our first step in measuring labor compensation is to provide a basis for converting average compensation per person to average compensation per job. For this purpose we construct matrices of weeks paid per year, cross-classified by sex, age, employment class, occupation, and industry for each year, using the multiproportional matrix model. The average number of weeks paid per year for each category of workers, divided by fifty-two, provides an estimate of the number of jobs per person in each category.

The second step in our measurement of labor compensation is to construct matrices giving average compensation per person for the civilian labor force for each postwar year, cross-classified by sex, age, education, employment class, occupation, and industry of employment. Marginal totals for average compensation are based on data on wage and salary income from the three last decennial Censuses of Population. These data are interpolated and extrapolated from the benchmark years to obtain estimates of wage and salary income for each year from 1947 to 1973. The wage and salary data for each year are adjusted to incorporate employers' contributions to social security and unemployment compensation and other supplements to wages and salaries. We divide average compensation per person by the ratio of the average number of weeks paid per year to fifty-two to obtain average compensation per job for each category of workers. The resulting compensation matrices are adjusted to control totals for labor compensation by industry from the U.S. national income and product accounts.

*Weeks*

In estimating labor compensation from census data it is essential to recall that the census provides an enumeration of persons on the basis of household surveys, while data on employment from establishment surveys provide an enumeration of jobs rather than persons. If a job is filled by two workers during a given year, each paid for twenty-six weeks, employment data from establishment surveys will report one person employed while compensation data from household surveys will report the compensation received by both workers. Multiplying average compensation per person in a given category by the number of jobs in that category would produce a downward bias in the resulting estimate of labor compensation. To eliminate this source of bias we divide average compensation per person by the number of jobs per person, estimated as the ratio of the number of weeks paid for each person to fifty-two. In our example, we would divide average compensation for each of our two workers by the ratio of twenty-six weeks paid for each worker to fifty-two to produce an average compensation per job equal to twice the average compensation per person.

The Bureau of the Census provides the only source of data on weeks cross-classified by demographic and industrial characteristics of the work force. As indicated in the following census definition, these data are compiled on a weeks-paid basis rather than on a weeks-worked basis.

> The data on weeks worked pertain to the number of different weeks in which a person did any work for pay or profit (including paid vacation and sick leave) or worked without pay on a family farm or in a family business.[21]

Census data on weeks paid from household surveys are compiled on the same basis as data on employment from establishment surveys, which include all jobs for which payment is made rather than the number of workers actually at work during the survey period. At this point we find it useful to emphasize that the employment matrices we have generated from household surveys are controlled to industry totals from establishment surveys.

A problem in the use of the weeks data arises from the census's policy of assigning all weeks for which a worker was paid during the past year to the cell representing that worker's present demographic and industrial characteristics. This may introduce a bias if the worker has crossed

21. U.S. Department of Commerce, Bureau of the Census, *U.S. Census of Population—1960. Industrial Characteristics*, PC(2)-7F, p. xvi.

occupation, class, or industry boundaries during the past year. The data constrain our options and allow us to do little more than acknowledge this limitation. However, two qualifying notes may be appended. First, according to Bancroft (1963), fewer than 6% of all employed persons actually crossed such boundaries in 1961.[22] While this percentage may shift over time, a second and more important finding of this same study of job mobility reveals that 96.7% of the job changes were self-canceling[23]—that is, except for 3.3% of the sample, job shifts away from each class-occupation-industry category were fully offset by employment shifts into the same category. Consequently, unless the cumulative weeks paid of workers leaving a particular job differ substantially from the weeks paid of incoming laborers, little bias is introduced by the census procedure.

Since the census reports weeks paid in the form of empirical frequency distributions, the steps used to construct weeks matrices are very similar to those used in deriving the hours-worked matrices. First, we assign each person to the appropriate cell. Assuming that weeks paid for the individuals in each cell have a lognormal distribution, we estimate the unknown parameters of this distribution from the empirical frequency distributions reported by the Bureau of the Census. No data are available on the weeks paid for multiple job holders for principal and secondary jobs; however, Perrella (1970) reports that almost half of all multiple job holders worked at both principal and secondary jobs in all twelve months preceding a survey taken in May 1969.[24] Accordingly, we assume that the average of weeks paid for multiple job holders is equal to the average number of weeks paid in each industry of employment.

The multiproportional matrix model is used in constructing a matrix of weeks paid for employed persons, cross-classified by sex, age, employment class, occupation, and industry. The matrix for each decennial census year is initialized by means of the corresponding employment matrix; all available marginal totals of weeks paid for each year are then incorporated. Matrices for intermediate years are initialized by a matrix with entries equal to the product of the entries from the corresponding employment matrix and a weighted average of entries from matrices of average weeks paid from the nearest years for which weeks matrices were available. No marginal totals were available for 1947 and 1948, so that we employ the matrix for average weeks paid for 1949 to represent the corresponding matrices for 1947 and 1948. Similarly, no marginal totals are available for 1971, so that we use an average of the matrices for average weeks paid for 1970 and 1972 to represent the

22. Bancroft (1963), tables F and G.
23. Ibid.
24. Perrella (1970), p. 3.

matrix for 1971. A procedure identical to that applied to hours worked was used to adjust the 1948–66 data on weeks worked for reallocation of the corporate self-employed to the wage and salary class.

*Labor Compensation*

The first problem in measuring labor compensation is the selection of a concept that reflects differences among the marginal products of individual workers. The available census compensation data include total income, earnings, and wage and salary earnings. Earnings include the return to capital invested by self-employed workers in their private businesses, as the following definition indicates:

> Earnings are the sum of wages and salary income and self-employment income. Self-employment income is defined as net money income (gross receipts minus operating expenses) from a business, farm, or professional enterprise in which the person was engaged on his own account.[25]

Earnings reflect differences in marginal products of workers, but also incorporate differences in income from the use of capital. The wage and salary income of wage and salary workers is a more appropriate starting point for the measurement of labor compensation.

A second problem in measuring labor compensation is that the cost of labor input from the point of view of the firm is the sum of both direct payments to labor in the form of wages and salaries and indirect payments that take the form of supplements. The Bureau of the Census reports compensation from the point of view of the household, so that the incomes reported are measures of wage and salary income rather than the total of wages, salaries, and supplements. Household surveys exclude employers' contributions to social security, pension plans, unemployment insurance, and all the other programs that are combined under the heading of supplements. Differentials in the proportion of supplements in labor compensation are sufficient to make suspect any assumption of proportionality of direct labor payments to total labor cost. For example, employers' contributions to social security and unemployment insurance are calculated by applying a percentage to each worker's annual earnings, but only up to a fixed maximum.

A third problem in measuring labor compensation concerns the appropriate time period for comparisons of the marginal productivities among distinct labor groups. A worker's average compensation per hour provides a good approximation to the worker's marginal productivity. Annual compensation, even based on labor earnings for each worker, is hardly an adequate proxy for compensation per hour, since

25. U.S. Department of Commerce, Bureau of the Census, *U.S. Census of Population—1960. Industrial Characteristics*, PC(2)-7F, p. xvi.

annual labor compensation is the product of annual hours and hourly compensation. Annual hours may differ widely among groups and over time. If annual hours worked vary over demographic and industrial groups, then differences in labor compensation based on variations in annual earnings do not parallel differences in marginal productivity. An appropriate measure of labor compensation requires estimates of average compensation per hour for each of the categories of labor to be aggregated.

The fourth problem in measuring labor compensation is whether weights based on compensation per hour worked should be fixed over the whole time period or should vary from year to year. To account for shifting demand conditions, changing production techniques, or the impact of constraints on labor supply, the best approach is to construct a set of weights based on compensation per hour worked for each year. We have undertaken the construction of measures of hourly compensation for each of the postwar years 1947 through 1973. Just as for data on hours and weeks, annual compensation data are presented in the form of empirical frequency distributions for the three benchmark years 1949, 1959, and 1969. Since economists investigating the distribution of labor income in the United States have long observed that the distributions can be approximated by a lognormal probability distribution, we have employed Gjeddebaek's adaptation of the method of maximum likelihood to estimate the parameters of this distribution. We have employed this method to estimate average wage and salary income for each category of labor input. It is important to note that this estimate refers to the wage and salary income of persons and not to the sum of wage payments to all workers occupying a given job.

Estimates based on Bureau of the Census data identify the amount of income workers receive and not the total labor cost incurred by the firm. To estimate labor cost we have distributed employers' contributions to social security among employees by adding to wage and salary income the appropriate dollar amount as determined by the workers' annual wages or salaries and the year's social security tax laws as described by Pechman (1971). Similarly, we added unemployment compensation contributions by employers to the wage and salary income matrices. These two adjustments account for nearly 70% of all earnings supplements.

Up to this point we have defined average labor compensation per person rather than average compensation per job. Two persons reporting $10,000 each for twenty-six weeks' work earn a different sum of supplements than a single laborer reporting $20,000 income for a full year's work. To convert the census data on average compensation per person to data on average compensation per job we divide average compensation for each category of worker by the ratio of the number of weeks paid to the number of weeks in a calendar year, fifty-two. The resulting matrices of annual labor compensation of wage and salary workers are inputs into the multiproportional matrix model.

Control totals for annual labor compensation by industry are taken directly from table 6.1 in the national income issue of the *Survey of Current Business*. These labor compensation data include all employer supplements. In addition to guaranteeing correct industry totals, these data provide the basis for the distribution of the 30% of labor supplements not accounted for directly. In addition, establishment-based control totals assure that the compensation of multiple job holders is appropriately distributed among each worker's industries of employment. Finally, the national income and product accounts provide a continuous time series of labor compensation for the period 1947 through 1973. The labor compensation matrix for each intermediate year is initialized by a matrix with entries equal to the product of annual hours worked for the corresponding cell and a weighted average of wages and salaries per hour worked for the nearest census years with weights given by log-linear interpolation.

The hourly wage estimates for the benchmark years include employers' contributions to social security and unemployment insurance as well as all payments to employee pension funds and similar programs. These payments vary from year to year depending on the current tax laws, union contracts, and so on. Failure to account for these changes would introduce a bias when using data reported for census years to estimate wage rates for intermediate years. To adjust wage data so that wage rates do not reflect employers' tax contributions and other indirect payments, a matrix of annual labor compensation is generated with all nontax supplements excluded. Second, a matrix of benchmark wage rates exclusive of each year's social security and unemployment insurance taxes paid by employers is generated. We initialize each intermediate year's compensation model with an initial estimate of annual wages excluding supplements.

We next estimate wage rates for each intermediate year. We first adjust the earnings estimates to reflect wage and salary totals, exclusive of employer supplements, published by the Bureau of Economic Analysis. Next we estimate the appropriate level of employer contributions to social security and unemployment insurance for each cell; to account for the remaining supplements we adjust data from all cells to control totals from the national income and product accounts. To obtain wages earned per hour worked, where wages represent the sum of the employers' direct and indirect payments to labor, we divide labor compensation by hours worked, defined by the product of employment, weekly hours worked, and the number of weeks per calendar year, fifty-two. Together with the decennial census matrices described above, these estimates for intermediate years form a complete time series of employers' direct plus indirect hourly payments to labor for the period 1947–73.

Since earnings reported to the census by self-employed laborers are a combination of labor income and the return to noncorporate capital, the procedure we have described for estimating labor compensation can be applied only to wage and salary workers. An index of labor input requires an estimate of the labor compensation of self-employed and unpaid family workers. Given the compensation of employees and noncorporate income by industry from the national income and product accounts, two options present themselves. Holding sex, age, education, occupation, and industry constant, we could assume that both classes of workers earn identical hourly wages. Using the employment, hours, and weeks matrices generated above, an estimated wage bill for the self-employed could be calculated for each industry. Subtracting this total from noncorporate income, we would obtain property compensation. Alternatively, we could assume that both corporate and noncorporate capital earn the same after-tax return. Noncorporate property income for each industry could then be subtracted from total noncorporate income to obtain labor compensation. The residual would represent the labor return to that industry's self-employed and unpaid family workers. This wage bill could be distributed among the self-employed so as to preserve the wage differentials observed among that industry's classified wage and salary workers.

We have chosen to assume that after-tax rates of return are the same for corporate and noncorporate business. Differences in individual preferences and barriers to entry of some wage and salary workers into the self-employed category are sufficient to make suspect any claim that wages are equal, even controlling for labor characteristics. By contrast, there is less reason to expect that immobility of capital results in differential after-tax rates of return in the corporate and noncorporate sectors. The cost of incorporating a noncorporate business is relatively modest, and small corporations can be treated in the same manner as noncorporate businesses from the point of view of the corporate income tax. The legal form of organization, corporate or noncorporate, can be altered with little impact on the use of capital, so that capital is freely mobile between sectors.

### 1.2.5 Indexes of Labor Input

We have outlined the development of data on annual hours worked and labor compensation per hour for each industrial sector, cross-classified by sex, age, education, employment class, and occupation of workers. To construct an index of labor input for each industrial sector we assume that sectoral labor input, say $\{L_i\}$, can be expressed as a translog function of its individual components, say $\{L_{li}\}$. The corresponding index of sectoral labor input is a translog quantity index of individual labor inputs:

$$\ln L_i(T) - \ln L_i(T-1) = \Sigma \bar{v}^i_{Ll} [\ln L_{li}(T) - \ln L_{li}(T-1)], \qquad (i = 1, 2, \ldots, n),$$

where weights are given by average shares of each component in the value of sectoral labor compensation:

$$\bar{v}^i_{Ll} = \frac{1}{2} [v^i_{Ll}(T) + v^i_{Ll}(T-1)], \qquad (i = 1, 2, \ldots, n; l = 1, 2, \ldots, q),$$

and

$$v^i_{Ll} = \frac{p^i_{Ll} L_{li}}{\Sigma p^i_{Ll} L_{li}}, \qquad (i = 1, 2, \ldots, n; l = 1, 2, \ldots, q).$$

The value shares are computed from data on hours worked $\{L_{li}\}$ and compensation per hour $\{p^i_{Ll}\}$ for each component of sectoral labor input, cross-classified by sex, age, education, employment class, and occupation of workers. Labor compensation for the sector as a whole $\Sigma p^i_{Ll} L_{li}$ is controlled to labor compensation by industry from the U.S. national income accounts.

For each of the components of labor input into an industrial sector $\{L_{li}(T)\}$, the flow of labor services is proportional to hours worked, say $\{H_{li}(T)\}$:

$$L_{li}(T) = Q^i_{Ll} H_{li}(T), \qquad (i = 1, 2, \ldots, n; l = 1, 2, \ldots, q),$$

where the constants of proportionality $\{Q^i_{Ll}\}$ transform hours worked into a flow of labor services. The translog quantity indexes of sectoral labor input $\{L_i\}$ can be expressed in terms of their components $\{L_{li}\}$ or in terms of the components of sectoral hours worked $\{H_{li}\}$:

$$\begin{aligned} \ln L_i(T) - \ln L_i(T-1) &= \Sigma \bar{v}^i_{Ll} [\ln L_{li}(T) - \ln L_{li}(T-1)] \\ &= \Sigma \bar{v}^i_{Ll} [\ln H_{li}(T) - \ln H_{li}(T-1)], \qquad (i = 1, 2, \ldots, n). \end{aligned}$$

We form sectoral indexes of labor input from data on hours worked by industry, cross-classified by sex, age, education, employment class, and occupation. Changes in the logarithms of hours worked for each component are weighted by average shares in sectoral labor compensation.

We can define *sectoral hours worked*, say $\{H_i(T)\}$, as the unweighted sum of its components,

$$H_i(T) = \sum H_{li}(T), \qquad (i = 1, 2, \ldots, n).$$

Similarly, we can define *sectoral indexes of the quality of hours worked*, say $\{Q^i_L(T)\}$, that transform sectoral measures of hours worked into the translog indexes of labor input:

$$L_i(T) = Q^i_L(T) H_i(T), \qquad (i = 1, 2, \ldots, n).$$

The sectoral indexes of the quality of hours worked can be expressed in the form

$$\begin{aligned} \ln Q^i_L(T) - \ln Q^i_L(T-1) \\ = \sum \bar{v}^i_{Ll} [\ln H_{li}(T) - \ln H_{li}(T-1)] \\ - [\ln H_i(T) - \ln H_i(T-1)], \\ (i = 1, 2, \ldots, n), \end{aligned}$$

so that these indexes reflect changes in the composition of hours worked within each sector.[26] Sectoral labor quality remains unchanged if all components of hours worked within a sector are growing at the same rate. Sectoral quality rises if components with higher flows of labor input per hour worked are growing more rapidly and falls if components with lower flows per hour worked are growing more rapidly.

We have generated translog indexes of labor input for each industrial sector listed in table 1.1. There are 1600 categories of labor input for each industry and 51 industries. Based on the employment, hours, weeks, and labor compensation data described above, translog indexes of labor input for the private domestic economy and for a number of sectoral divisions are presented in column (4) of tables 1.2 through 1.13. Unweighted indexes of hours worked based on the same data are given in column (2). The ratio between these two series, presented in column (3), measures the change in labor quality. To facilitate comparisons with unweighted and industry-weighted hours indexes, industry series employed by the Bureau of Labor Statistics and by Kendrick are presented in columns (1) and (5). Kendrick's labor indexes have been taken directly from his *Postwar Productivity Trends in the United States: 1948–1969*.[27]

26. Detailed discussions of quality indexes and applications to disaggregated labor data can be found in doctoral dissertations by Barger (1971) and Chinloy (1974).

27. See Kendrick (1973), pp. 240–359. For a complete discussion of his methods, see pages 154–58 of the same book.

The primary source of hours and employment estimates for the BLS productivity studies is the Department of Labor's Current Employment Statistics Program. Establishment data on employment and average paid weekly hours of production workers in manufacturing and nonsupervisory workers in nonmanufacturing are developed from this program and published in BLS (1973*a*) Bulletin no. 1312, "Employment and Earnings Statistics of the United States." The methods currently adopted by BLS in constructing its hours series have evolved considerably from the original procedures outlined in BLS (1960) Bulletin no. 1249. A working paper describing these methods is available on request from the Productivity and Technology Division of the Bureau of Labor Statistics. The following passage has been extracted from this working paper and, along with published and unpublished man-hours data made available by BLS, forms the basis for the indexes found in column (1):

> In the manufacturing sector, separate estimates for production and nonproduction worker manhours are derived and then aggregated to the manufacturing total. Production workers and nonproduction worker employment and production worker average weekly hours are taken directly from published sources (BLS Bulletin 1312). Average weekly hours for nonproduction workers are developed from BLS studies of wages and supplements in the manufacturing sector which provide data on the regularly scheduled workweek of white collar employees. It is assumed that scheduled hours are equivalent to paid hours for nonproduction workers in manufacturing. . . .
>
> For nonmanufacturing sectors, employment and weekly hours paid are taken from published sources (BLS Bulletin 1312) . . . . Although average weekly hours data refer only to nonsupervisory workers (who comprise about 85 percent of total employment), it is assumed that the length of the workweek for nonsupervisory workers in each nonmanufacturing industry is the same for all wage and salary workers.
>
> Manhours are computed by multiplying employment by average weekly hours in each sector and inflated to annual levels using a constant factor of 52. Each manhour is treated as a homogeneous unit; no distortion is made between workers with different skill levels or rates of pay.[28]

28. U.S. Bureau of Labor Statistics (1973*b*), p. 3. The scheduled weekly hours for nonproduction workers are calculated from data collected by BLS for the study, *Employer Expenditures for Selected Supplementary Remuneration Practices for Production Workers in Manufacturing Industries, 1962*, BLS Bulletin 1428 (1965).

While not mentioned in this excerpt, estimated annual man-hours for proprietors and unpaid family workers are derived by BLS from the National Income Accounts and the Current Population Survey and are added to industry employee totals. The BLS indexes presented in column (1) of tables 1.2 through 1.16 similarly include these estimates.

**Table 1.2** **Private Domestic Economy (1972=1.000)**

| Year | Hours Worked |  | Labor | Labor Input |  |
|---|---|---|---|---|---|
|  | BLS | MPM Model | Quality | Translog | Kendrick |
|  | (1) | (2) | (3) | (4) | (5) |
| 1947 | .821 | .855 | .846 | .723 | .771 |
| 1948 | .823 | .859 | .851 | .730 | .781 |
| 1949 | .794 | .823 | .850 | .700 | .746 |
| 1950 | .806 | .845 | .861 | .728 | .766 |
| 1951 | .836 | .877 | .871 | .763 | .806 |
| 1952 | .844 | .880 | .886 | .780 | .817 |
| 1953 | .855 | .889 | .893 | .794 | .825 |
| 1954 | .822 | .856 | .895 | .766 | .784 |
| 1955 | .855 | .880 | .897 | .790 | .814 |
| 1956 | .866 | .893 | .902 | .806 | .829 |
| 1957 | .855 | .880 | .911 | .802 | .824 |
| 1958 | .818 | .847 | .912 | .773 | .784 |
| 1959 | .848 | .872 | .920 | .802 | .813 |
| 1960 | .854 | .871 | .947 | .825 | .822 |
| 1961 | .841 | .865 | .934 | .809 | .811 |
| 1962 | .858 | .881 | .951 | .838 | .830 |
| 1963 | .863 | .887 | .953 | .846 | .841 |
| 1964 | .877 | .899 | .963 | .866 | .860 |
| 1965 | .907 | .927 | .967 | .896 | .890 |
| 1966 | .929 | .952 | .981 | .934 | .927 |
| 1967 | .935 | .957 | .987 | .944 | .932 |
| 1968 | .954 | .970 | .993 | .964 | .951 |
| 1969 | .978 | .994 | .995 | .989 | .978 |
| 1970 | .966 | .975 | 1.007 | .983 |  |
| 1971 | .966 | .972 | 1.006 | .978 |  |
| 1972 | 1.000 | 1.000 | 1.000 | 1.000 |  |
| 1973 | 1.033 | 1.040 | 1.006 | 1.046 |  |

Table 1.3 **Agriculture (1972=1.000)**

| Year | Hours Worked BLS (1) | Hours Worked MPM Model (2) | Labor Quality (3) | Labor Input Translog (4) | Labor Input Kendrick (5) |
|---|---|---|---|---|---|
| 1947 | 2.491 | 2.542 | .921 | 2.341 | 2.736 |
| 1948 | 2.387 | 2.456 | .904 | 2.221 | 2.662 |
| 1949 | 2.361 | 2.349 | .912 | 2.142 | 2.671 |
| 1950 | 2.176 | 2.289 | .934 | 2.137 | 2.462 |
| 1951 | 2.068 | 2.190 | .916 | 2.007 | 2.329 |
| 1952 | 1.972 | 2.111 | .932 | 1.968 | 2.211 |
| 1953 | 1.926 | 2.064 | .929 | 1.916 | 2.057 |
| 1954 | 1.874 | 2.013 | .933 | 1.877 | 1.993 |
| 1955 | 1.918 | 1.952 | .931 | 1.817 | 2.026 |
| 1956 | 1.814 | 1.825 | .933 | 1.703 | 1.934 |
| 1957 | 1.691 | 1.692 | .933 | 1.579 | 1.771 |
| 1958 | 1.575 | 1.619 | .939 | 1.520 | 1.641 |
| 1959 | 1.573 | 1.592 | .939 | 1.495 | 1.638 |
| 1960 | 1.553 | 1.506 | .974 | 1.467 | 1.609 |
| 1961 | 1.460 | 1.472 | .944 | 1.390 | 1.505 |
| 1962 | 1.405 | 1.437 | .958 | 1.376 | 1.469 |
| 1963 | 1.328 | 1.381 | .945 | 1.304 | 1.389 |
| 1964 | 1.280 | 1.293 | .955 | 1.235 | 1.334 |
| 1965 | 1.249 | 1.258 | .965 | 1.213 | 1.300 |
| 1966 | 1.139 | 1.139 | .988 | 1.125 | 1.182 |
| 1967 | 1.131 | 1.091 | .998 | 1.088 | 1.142 |
| 1968 | 1.115 | 1.081 | 1.000 | 1.080 | 1.116 |
| 1969 | 1.047 | 1.048 | .999 | 1.047 | 1.047 |
| 1970 | .995 | 1.015 | 1.026 | 1.042 | |
| 1971 | .983 | .997 | .999 | .997 | |
| 1972 | 1.000 | 1.000 | 1.000 | 1.000 | |
| 1973 | .987 | 1.004 | 1.007 | 1.011 | |

**Table 1.4** **Mining (1972=1.000)**

| Year | Hours Worked: BLS (1) | Hours Worked: MPM Model (2) | Labor Quality (3) | Labor Input: Translog (4) | Labor Input: Kendrick (5) |
|---|---|---|---|---|---|
| 1947 | 1.447 | 1.439 | .868 | 1.249 | |
| 1948 | 1.453 | 1.520 | .871 | 1.323 | 1.542 |
| 1949 | 1.258 | 1.316 | .872 | 1.148 | 1.314 |
| 1950 | 1.274 | 1.372 | .878 | 1.205 | 1.373 |
| 1951 | 1.332 | 1.416 | .882 | 1.249 | 1.404 |
| 1952 | 1.297 | 1.379 | .893 | 1.232 | 1.363 |
| 1953 | 1.259 | 1.333 | .899 | 1.199 | 1.301 |
| 1954 | 1.154 | 1.206 | .903 | 1.089 | 1.168 |
| 1955 | 1.214 | 1.267 | .905 | 1.148 | 1.236 |
| 1956 | 1.259 | 1.332 | .910 | 1.213 | 1.297 |
| 1957 | 1.246 | 1.305 | .917 | 1.197 | 1.269 |
| 1958 | 1.099 | 1.138 | .929 | 1.057 | 1.098 |
| 1959 | 1.114 | 1.123 | .935 | 1.051 | 1.088 |
| 1960 | 1.082 | 1.089 | .939 | 1.023 | 1.059 |
| 1961 | 1.027 | 1.044 | .947 | .988 | 1.009 |
| 1962 | 1.004 | 1.026 | .958 | .982 | .996 |
| 1963 | .997 | 1.007 | .956 | .963 | .985 |
| 1964 | 1.002 | 1.006 | .964 | .970 | .985 |
| 1965 | 1.007 | 1.019 | .964 | .983 | 1.000 |
| 1966 | 1.008 | 1.021 | .971 | .991 | 1.000 |
| 1967 | .985 | .992 | .974 | .966 | .975 |
| 1968 | .974 | .986 | .980 | .966 | .969 |
| 1969 | 1.001 | 1.014 | .987 | 1.000 | 1.001 |
| 1970 | 1.004 | 1.013 | .991 | 1.004 | |
| 1971 | .969 | .982 | 1.004 | .985 | |
| 1972 | 1.000 | 1.000 | 1.000 | 1.000 | |
| 1973 | 1.026 | 1.023 | 1.000 | 1.023 | |

**Table 1.5 Contract Construction (1972=1.000)**

| Year | Hours Worked | | Labor Quality | Labor Input | |
|---|---|---|---|---|---|
| | BLS (1) | MPM Model (2) | (3) | Translog (4) | Kendrick (5) |
| 1947 | .692 | .682 | .895 | .611 | |
| 1948 | .738 | .728 | .907 | .661 | .732 |
| 1949 | .722 | .693 | .908 | .629 | .697 |
| 1950 | .765 | .748 | .909 | .679 | .749 |
| 1951 | .824 | .810 | .917 | .743 | .810 |
| 1952 | .834 | .822 | .927 | .762 | .826 |
| 1953 | .806 | .796 | .929 | .740 | .792 |
| 1954 | .760 | .760 | .934 | .709 | .749 |
| 1955 | .789 | .777 | .937 | .728 | .767 |
| 1956 | .837 | .817 | .935 | .764 | .806 |
| 1957 | .811 | .790 | .935 | .739 | .782 |
| 1958 | .767 | .760 | .939 | .713 | .752 |
| 1959 | .810 | .790 | .941 | .744 | .781 |
| 1960 | .790 | .775 | .943 | .731 | .767 |
| 1961 | .779 | .777 | .947 | .736 | .766 |
| 1962 | .801 | .797 | .961 | .766 | .783 |
| 1963 | .819 | .819 | .963 | .788 | .805 |
| 1964 | .837 | .843 | .973 | .820 | .828 |
| 1965 | .872 | .879 | .973 | .856 | .866 |
| 1966 | .890 | .901 | .983 | .886 | .891 |
| 1967 | .872 | .897 | .988 | .886 | .879 |
| 1968 | .880 | .920 | .995 | .915 | .891 |
| 1969 | .950 | .969 | .997 | .966 | .950 |
| 1970 | .929 | .941 | .987 | .928 | |
| 1971 | .961 | .961 | 1.011 | .971 | |
| 1972 | 1.000 | 1.000 | 1.000 | 1.000 | |
| 1973 | 1.051 | 1.072 | 1.004 | 1.076 | |

**Table 1.6 Manufacturing (1972=1.000)**

| Year | Hours Worked | | Labor Quality | Labor Input | |
|---|---|---|---|---|---|
| | BLS (1) | MPM Model (2) | (3) | Translog (4) | Kendrick (5) |
| 1947 | .814 | .821 | .873 | .716 | |
| 1948 | .825 | .840 | .874 | .734 | .819 |
| 1949 | .750 | .767 | .876 | .671 | .745 |
| 1950 | .812 | .829 | .880 | .729 | .800 |
| 1951 | .875 | .896 | .888 | .795 | .872 |
| 1952 | .890 | .913 | .903 | .824 | .891 |
| 1953 | .932 | .951 | .911 | .867 | .930 |
| 1954 | .852 | .872 | .918 | .800 | .849 |
| 1955 | .898 | .919 | .917 | .843 | .893 |
| 1956 | .912 | .932 | .921 | .858 | .906 |
| 1957 | .897 | .916 | .928 | .850 | .897 |
| 1958 | .824 | .836 | .936 | .782 | .813 |
| 1959 | .879 | .892 | .938 | .836 | .871 |
| 1960 | .874 | .886 | .956 | .847 | .873 |
| 1961 | .850 | .865 | .951 | .823 | .848 |
| 1962 | .885 | .903 | .964 | .870 | .888 |
| 1963 | .894 | .911 | .961 | .875 | .898 |
| 1964 | .913 | .929 | .966 | .897 | .927 |
| 1965 | .960 | .978 | .963 | .942 | .969 |
| 1966 | 1.021 | 1.043 | .972 | 1.014 | 1.039 |
| 1967 | 1.018 | 1.041 | .981 | 1.022 | 1.015 |
| 1968 | 1.040 | 1.053 | .985 | 1.038 | 1.037 |
| 1969 | 1.055 | 1.070 | .986 | 1.055 | 1.055 |
| 1970 | 1.000 | 1.002 | .994 | .996 | |
| 1971 | .961 | .960 | 1.007 | .967 | |
| 1972 | 1.000 | 1.000 | 1.000 | 1.000 | |
| 1973 | 1.053 | 1.057 | 1.000 | 1.057 | |

**Table 1.7** **Transportation (1972=1.000)**

| Year | Hours Worked: BLS (1) | Hours Worked: MPM Model (2) | Labor Quality (3) | Labor Input: Translog (4) | Labor Input: Kendrick (5) |
|---|---|---|---|---|---|
| 1947 | 1.126 | 1.138 | .943 | 1.072 | |
| 1948 | 1.128 | 1.156 | .950 | 1.098 | 1.255 |
| 1949 | 1.025 | 1.054 | .947 | .998 | 1.130 |
| 1950 | .992 | 1.041 | .938 | .976 | 1.105 |
| 1951 | 1.049 | 1.099 | .944 | 1.038 | 1.169 |
| 1952 | 1.043 | 1.088 | .952 | 1.035 | 1.157 |
| 1953 | 1.054 | 1.088 | .953 | 1.037 | 1.141 |
| 1954 | .986 | 1.014 | .952 | .965 | 1.044 |
| 1955 | 1.013 | 1.035 | .953 | .986 | 1.068 |
| 1956 | 1.035 | 1.049 | .953 | 1.000 | 1.080 |
| 1957 | 1.030 | 1.034 | .955 | .988 | 1.062 |
| 1958 | .946 | .951 | .956 | .909 | .959 |
| 1959 | .974 | .966 | .960 | .927 | .969 |
| 1960 | .961 | .954 | .963 | .919 | .959 |
| 1961 | .932 | .931 | .964 | .898 | .926 |
| 1962 | .939 | .935 | .974 | .911 | .925 |
| 1963 | .936 | .937 | .972 | .911 | .928 |
| 1964 | .951 | .949 | .980 | .930 | .944 |
| 1965 | .970 | .968 | .977 | .945 | .961 |
| 1966 | .988 | .996 | .988 | .984 | .990 |
| 1967 | .991 | 1.002 | .994 | .996 | .985 |
| 1968 | 1.004 | 1.016 | 1.001 | 1.017 | 1.006 |
| 1969 | 1.015 | 1.026 | 1.002 | 1.029 | 1.015 |
| 1970 | 1.010 | 1.006 | .999 | 1.005 | |
| 1971 | .986 | .994 | 1.013 | 1.006 | |
| 1972 | 1.000 | 1.000 | 1.000 | 1.000 | |
| 1973 | 1.030 | 1.027 | 1.008 | 1.035 | |

**Table 1.8** **Communications and Public Utilities (1972=1.000)**

| Year | Hours Worked: BLS (1) | Hours Worked: MPM Model (2) | Labor Quality (3) | Labor Input: Translog (4) | Labor Input: Kendrick (5) |
|---|---|---|---|---|---|
| 1947 | .770 | .642 | .854 | .548 | |
| 1948 | .783 | .693 | .859 | .596 | .681 |
| 1949 | .760 | .688 | .861 | .593 | .680 |
| 1950 | .777 | .687 | .864 | .593 | .679 |
| 1951 | .806 | .714 | .870 | .622 | .706 |
| 1952 | .814 | .724 | .884 | .640 | .714 |
| 1953 | .819 | .746 | .885 | .660 | .738 |
| 1954 | .788 | .754 | .899 | .678 | .743 |
| 1955 | .808 | .770 | .902 | .695 | .759 |
| 1956 | .818 | .802 | .903 | .724 | .790 |
| 1957 | .813 | .808 | .907 | .733 | .795 |
| 1958 | .778 | .780 | .919 | .717 | .773 |
| 1959 | .775 | .773 | .931 | .719 | .768 |
| 1960 | .781 | .779 | .954 | .743 | .779 |
| 1961 | .772 | .774 | .948 | .733 | .769 |
| 1962 | .774 | .774 | .961 | .744 | .772 |
| 1963 | .776 | .779 | .964 | .751 | .777 |
| 1964 | .794 | .795 | .975 | .775 | .793 |
| 1965 | .821 | .821 | .976 | .801 | .819 |
| 1966 | .851 | .851 | .979 | .833 | .851 |
| 1967 | .863 | .868 | .989 | .858 | |
| 1968 | .879 | .882 | .992 | .875 | |
| 1969 | .932 | .939 | .995 | .934 | |
| 1970 | .968 | .988 | .994 | .982 | |
| 1971 | .957 | .980 | 1.010 | .990 | |
| 1972 | 1.000 | 1.000 | 1.000 | 1.000 | |
| 1973 | 1.031 | 1.031 | 1.003 | 1.034 | |

**Table 1.9** **Trade (1972=1.000)**

| Year | Hours Worked BLS (1) | Hours Worked MPM Model (2) | Labor Quality (3) | Labor Input Translog (4) | Labor Input Kendrick (5) |
|---|---|---|---|---|---|
| 1947 | .715 | .795 | .936 | .744 | |
| 1948 | .726 | .776 | .944 | .733 | .725 |
| 1949 | .727 | .774 | .945 | .732 | .720 |
| 1950 | .734 | .779 | .948 | .738 | .730 |
| 1951 | .759 | .815 | .946 | .770 | .762 |
| 1952 | .770 | .819 | .953 | .780 | .770 |
| 1953 | .773 | .819 | .955 | .782 | .768 |
| 1954 | .767 | .811 | .954 | .773 | .759 |
| 1955 | .791 | .831 | .947 | .786 | .782 |
| 1956 | .807 | .852 | .936 | .798 | .799 |
| 1957 | .803 | .849 | .939 | .797 | .801 |
| 1958 | .793 | .841 | .939 | .789 | .795 |
| 1959 | .815 | .855 | .943 | .807 | .813 |
| 1960 | .828 | .862 | .978 | .842 | .828 |
| 1961 | .815 | .855 | .955 | .817 | .820 |
| 1962 | .822 | .859 | .972 | .835 | .825 |
| 1963 | .824 | .860 | .975 | .838 | .832 |
| 1964 | .843 | .878 | .978 | .859 | .851 |
| 1965 | .872 | .901 | .976 | .880 | .875 |
| 1966 | .887 | .915 | .991 | .907 | .895 |
| 1967 | .894 | .914 | .994 | .909 | .899 |
| 1968 | .914 | .926 | 1.001 | .927 | .914 |
| 1969 | .937 | .954 | .995 | .949 | .937 |
| 1970 | .948 | .963 | 1.018 | .980 | |
| 1971 | .966 | .981 | 1.011 | .992 | |
| 1972 | 1.000 | 1.000 | 1.000 | 1.000 | |
| 1973 | 1.024 | 1.026 | 1.007 | 1.033 | |

**Table 1.10** **Finance, Insurance, and Real Estate (1972=1.000)**

| Year | Hours Worked | | Labor Quality | Labor Input | |
|---|---|---|---|---|---|
| | BLS (1) | MPM Model (2) | (3) | Translog (4) | Kendrick (5) |
| 1947 | .476 | .480 | .873 | .419 | |
| 1948 | .492 | .500 | .877 | .439 | .486 |
| 1949 | .493 | .501 | .878 | .440 | .490 |
| 1950 | .506 | .519 | .870 | .452 | .507 |
| 1951 | .530 | .543 | .885 | .481 | .532 |
| 1952 | .557 | .565 | .901 | .509 | .558 |
| 1953 | .580 | .590 | .913 | .539 | .583 |
| 1954 | .606 | .614 | .922 | .566 | .606 |
| 1955 | .627 | .635 | .922 | .586 | .624 |
| 1956 | .635 | .655 | .919 | .602 | .635 |
| 1957 | .643 | .664 | .923 | .613 | .645 |
| 1958 | .657 | .673 | .928 | .625 | .663 |
| 1959 | .675 | .689 | .942 | .649 | .679 |
| 1960 | .693 | .703 | .981 | .690 | .694 |
| 1961 | .704 | .722 | .962 | .694 | .707 |
| 1962 | .729 | .736 | .976 | .718 | .727 |
| 1963 | .751 | .755 | .976 | .737 | .750 |
| 1964 | .767 | .774 | .986 | .763 | .763 |
| 1965 | .782 | .799 | .987 | .789 | .785 |
| 1966 | .804 | .823 | .997 | .820 | .810 |
| 1967 | .822 | .846 | .991 | .838 | .828 |
| 1968 | .857 | .884 | .994 | .878 | .856 |
| 1969 | .902 | .923 | .990 | .914 | .902 |
| 1970 | .922 | .941 | .999 | .940 | |
| 1971 | .957 | .971 | 1.009 | .980 | |
| 1972 | 1.000 | 1.000 | 1.000 | 1.000 | |
| 1973 | 1.028 | 1.053 | 1.011 | 1.064 | |

**Table 1.11** **Services, Excluding Private Households and Nonprofit Institutions and Including Government Enterprises (1972=1.000)**

| Year | Hours Worked: BLS (1) | Hours Worked: MPM Model (2) | Labor Quality (3) | Labor Input: Translog (4) | Labor Input: Kendrick (5) |
|---|---|---|---|---|---|
| 1947 | .457 | .504 | .977 | .492 | |
| 1948 | .456 | .512 | .981 | .502 | .525 |
| 1949 | .458 | .513 | .985 | .505 | .523 |
| 1950 | .455 | .519 | 1.004 | .521 | .524 |
| 1951 | .472 | .537 | .988 | .530 | .529 |
| 1952 | .498 | .555 | .997 | .553 | .559 |
| 1953 | .505 | .565 | .998 | .563 | .567 |
| 1954 | .516 | .569 | 1.003 | .571 | .565 |
| 1955 | .520 | .585 | .993 | .581 | .578 |
| 1956 | .529 | .611 | .988 | .604 | .595 |
| 1957 | .546 | .629 | .991 | .623 | .610 |
| 1958 | .546 | .638 | .993 | .634 | .612 |
| 1959 | .569 | .660 | .994 | .655 | .630 |
| 1960 | .602 | .680 | 1.025 | .697 | .660 |
| 1961 | .625 | .702 | .998 | .700 | .672 |
| 1962 | .653 | .725 | 1.010 | .732 | .687 |
| 1963 | .685 | .749 | 1.004 | .752 | .708 |
| 1964 | .711 | .779 | 1.006 | .784 | .726 |
| 1965 | .751 | .808 | 1.004 | .811 | .759 |
| 1966 | .786 | .847 | 1.003 | .849 | .786 |
| 1967 | .813 | .873 | 1.006 | .878 | |
| 1968 | .854 | .897 | 1.007 | .903 | |
| 1969 | .903 | .935 | 1.007 | .941 | |
| 1970 | .937 | .944 | 1.027 | .969 | |
| 1971 | .958 | .960 | 1.009 | .968 | |
| 1972 | 1.000 | 1.000 | 1.000 | 1.000 | |
| 1973 | 1.038 | 1.047 | 1.003 | 1.050 | |

**Table 1.12 Private Households and Nonprofit Institutions (1972=1.000)**

| Year | Hours Worked: BLS (1) | Hours Worked: MPM Model (2) | Labor Quality (3) | Labor Input: Translog (4) | Labor Input: Kendrick (5) |
|---|---|---|---|---|---|
| 1947 | .820 | .842 | .815 | .687 | |
| 1948 | .816 | .853 | .824 | .703 | .668 |
| 1949 | .818 | .854 | .831 | .710 | .675 |
| 1950 | .876 | .905 | .835 | .756 | .716 |
| 1951 | .901 | .889 | .841 | .748 | .720 |
| 1952 | .887 | .833 | .857 | .714 | .713 |
| 1953 | .895 | .823 | .863 | .710 | .733 |
| 1954 | .865 | .778 | .877 | .682 | .699 |
| 1955 | .970 | .869 | .856 | .744 | .756 |
| 1956 | 1.023 | .909 | .849 | .771 | .781 |
| 1957 | 1.027 | .906 | .857 | .776 | .794 |
| 1958 | 1.048 | .931 | .855 | .797 | .820 |
| 1959 | 1.056 | .947 | .870 | .824 | .840 |
| 1960 | 1.077 | .980 | .902 | .884 | .885 |
| 1961 | 1.075 | .986 | .899 | .886 | .895 |
| 1962 | 1.084 | 1.002 | .916 | .918 | .914 |
| 1963 | 1.080 | 1.000 | .922 | .922 | .941 |
| 1964 | 1.074 | 1.000 | .931 | .931 | .955 |
| 1965 | 1.056 | .994 | .942 | .936 | .991 |
| 1966 | 1.031 | .994 | .957 | .952 | 1.031 |
| 1967 | 1.057 | 1.058 | .953 | 1.009 | |
| 1968 | 1.051 | 1.040 | .971 | 1.010 | |
| 1969 | 1.034 | 1.047 | .986 | 1.033 | |
| 1970 | 1.008 | 1.004 | .999 | 1.003 | |
| 1971 | .997 | 1.003 | 1.005 | 1.008 | |
| 1972 | 1.000 | 1.000 | 1.000 | 1.000 | |
| 1973 | .984 | .982 | 1.016 | .997 | |

**Table 1.13** General Government, Private Households, and Nonprofit Institutions (1972=1.000)

| Year | Hours Worked: BLS (1) | Hours Worked: MPM Model (2) | Labor Quality (3) | Labor Input: Translog (4) | Labor Input: Kendrick (5) |
|---|---|---|---|---|---|
| 1947 | .483 | .521 | .847 | .441 | .443 |
| 1948 | .491 | .535 | .851 | .455 | .449 |
| 1949 | .500 | .554 | .856 | .474 | .470 |
| 1950 | .523 | .576 | .853 | .491 | .489 |
| 1951 | .555 | .603 | .882 | .531 | .585 |
| 1952 | .561 | .604 | .913 | .551 | .622 |
| 1953 | .566 | .604 | .914 | .552 | .623 |
| 1954 | .568 | .597 | .932 | .556 | .615 |
| 1955 | .602 | .629 | .917 | .577 | .624 |
| 1956 | .638 | .656 | .913 | .599 | .637 |
| 1957 | .658 | .670 | .926 | .620 | .649 |
| 1958 | .675 | .689 | .927 | .639 | .658 |
| 1959 | .694 | .704 | .934 | .657 | .666 |
| 1960 | .711 | .726 | .948 | .688 | .683 |
| 1961 | .727 | .750 | .950 | .712 | .699 |
| 1962 | .743 | .767 | .965 | .740 | .730 |
| 1963 | .764 | .785 | .967 | .759 | .746 |
| 1964 | .780 | .806 | .973 | .784 | .766 |
| 1965 | .816 | .829 | .979 | .812 | .791 |
| 1966 | .847 | .864 | .984 | .850 | .845 |
| 1967 | .893 | .905 | .985 | .891 | .892 |
| 1968 | .912 | .924 | .998 | .922 | .925 |
| 1969 | .927 | .945 | .998 | .942 | .942 |
| 1970 | .935 | .951 | .995 | .946 | |
| 1971 | .965 | .974 | 1.005 | .979 | |
| 1972 | 1.000 | 1.000 | 1.000 | 1.000 | |
| 1973 | 1.018 | 1.018 | 1.010 | 1.028 | |

A comparison of rates of growth in BLS, Kendrick, and translog indexes of labor input over the 1948–66 period is presented for all fifty-one industries in table 1.14. In addition, rates of growth of the translog indexes of sectoral labor input are presented for five subperiods of the period 1947–73. Rates of growth of labor input for the period as a whole are also reported in table 1.14.

## 1.3 Capital Input

### 1.3.1 Introduction

Our next objective is to construct measures of capital input by industrial sector for the U.S. economy in current and constant prices. Our measures of capital input in constant prices are index numbers constructed from data on the services of capital stocks and rental prices for capital services. At a conceptual level these indexes are strictly analogous to the measures of labor input in constant prices presented in the preceding section. Capital input takes the form of services of capital stock just as labor input involves the services of the work force. Capital services are compensated at rental prices just as labor services are compensated at wage rates. Pursuing this analogy, a possible approach to construction of measures of capital input would be to compile data on rental transactions in capital services. This method provides the basis for measuring capital services associated with the use of dwellings in the U.S. national income and product accounts. Data on rental prices for tenant-occupied dwellings are used to measure rental prices for owner-occupied dwellings. Data on the stock of both tenant-occupied and owner-occupied dwellings are used in constructing estimates of the rental value of housing.

A substantial portion of the assets employed in the U.S. economy involves capital goods with active rental markets. Most types of land and structures can be rented, and a rental market exists for many types of equipment—transportation equipment, construction equipment, electronic computers, office equipment and furniture, and so on. Unfortunately, very little effort has been devoted to compiling data from rental transactions, so that the construction of measures of capital input based on sources analogous to those we have employed for labor input is not feasible. An alternative approach is to infer the level of capital stocks at each point of time from data on flows of investment up to that point. Rental prices required for indexes of capital input in constant prices can be inferred from data on prices of investment goods and on property compensation. To construct measures of capital input that are consistent with the U.S. national income and product accounts, we have controlled our data on investment by industrial sector to totals for all

**Table 1.14** **Labor Input: Rates of Growth**

| Industry | 1948–1966 (average annual rates of growth) BLS | Kendrick | Translog | Translog Index of Labor Input (average annual rates of growth) 1947–1973 | 1947–1953 | 1953–1957 | 1957–1960 | 1960–1966 | 1966–1973 |
|---|---|---|---|---|---|---|---|---|---|
| Agricultural production | | | −.0408 | −.0352 | −.0357 | −.0505 | −.0251 | −.0495 | −.0183 |
| Agricultural services | | | .0133 | .0202 | .0158 | −.0098 | −.0353 | .0492 | .0402 |
| Metal mining | −.0107 | −.0096 | −.0031 | −.0025 | .0204 | .0035 | −.0457 | −.0070 | −.0031 |
| Coal mining | −.0696 | −.0689 | −.0683 | −.0391 | −.0789 | −.0569 | −.1227 | −.0189 | .0236 |
| Crude petroleum and natural gas | .0053 | .0065 | .0141 | .0155 | .0602 | .0332 | −.0322 | −.0046 | .0046 |
| Nonmetallic mining and quarrying | .0126 | .0134 | .0160 | .0101 | .0304 | .0159 | −.0138 | .0178 | −.0070 |
| Contract construction | .0104 | .0109 | .0163 | .0218 | .0320 | −.0003 | −.0033 | .0319 | .0277 |
| Food and kindred products | −.0028 | | −.0005 | .0044 | .0272 | −.0081 | −.0016 | .0025 | −.0039 |
| Tobacco manufacturers | −.0157 | −.0082 | −.0015 | −.0028 | .0098 | −.0166 | .0078 | −.0083 | −.0054 |
| Textile mill products | −.0147 | −.0148 | −.0121 | −.0061 | −.0210 | −.0392 | −.0087 | .0158 | .0079 |
| Apparel and other fabr. textile prod. | .0099 | .0081 | .0085 | .0081 | .0148 | −.0120 | .0101 | .0227 | .0005 |
| Paper and allied products | .0193 | .0185 | .0256 | .0206 | .0301 | .0174 | .0230 | .0264 | .0084 |
| Printing and publishing | .0157 | .0135 | .0196 | .0174 | .0220 | .0137 | .0360 | .0137 | .0107 |
| Chemicals and allied products | .0212 | .0206 | .0312 | .0206 | .0206 | .0240 | .0214 | .0284 | .0117 |
| Petroleum and coal products | −.0107 | −.0133 | −.0024 | .0001 | .0160 | .0045 | −.0306 | −.0159 | .0107 |
| Rubber and misc. plastic products | .0300 | .0301 | .0343 | .0396 | .0557 | .0130 | .0114 | .0555 | .0395 |

**Table 1.14** (continued)

| Industry | 1948–1966 (average annual rates of growth) | | | Translog Index of Labor Input (average annual rates of growth) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | BLS | Kendrick | Translog | 1947–1973 | 1947–1953 | 1953–1957 | 1957–1960 | 1960–1966 | 1966–1973 |
| Leather and leather products | —.0053 | —.0048 | —.0043 | —.0110 | —.0052 | —.0109 | —.0098 | .0046 | —.0300 |
| Lumber and wood prod. excluding furniture | —.0151 | —.0160 | —.0147 | .0042 | .0373 | —.0474 | —.0077 | .0068 | .0081 |
| Furniture and fixtures | .0164 | .0132 | .0165 | —.0015 | —.0589 | —.0031 | .0005 | .0358 | .0157 |
| Stone, clay and glass products | .0101 | .0073 | .0143 | .0169 | .0287 | .0055 | .0192 | .0176 | .0119 |
| Primary metal industries | .0045 | .0033 | .0096 | .0053 | .0178 | —.0088 | —.0295 | .0283 | —.0022 |
| Fabricated metal industries | .0195 | .0168 | .0217 | .0177 | .0309 | .0017 | —.0081 | .0341 | .0126 |
| Machinery excluding electrical | .0200 | .0196 | .0240 | .0155 | .0116 | —.0045 | —.0184 | .0547 | .0112 |
| Electrical machinery, eqpt., and supplies | .0370 | .0366 | .0436 | .0350 | .0717 | .0062 | .0391 | .0474 | .0077 |
| Trans. eqpt. and ord. ex. motor vehicles | .0539 | | .0616 | .0349 | .1635 | .0022 | —.0517 | .0454 | —.0284 |
| Motor vehicles and equipment | .0091 | | .0165 | .0161 | .0472 | —.0420 | —.0148 | .0393 | .0159 |
| Prof. photographic eqpt. and watches | .0289 | .0308 | .0384 | .0400 | .0984 | .0144 | .0100 | .0380 | .0190 |
| Misc. manufacturing industries | .0007 | .0005 | .0057 | .0129 | .0420 | —.0212 | .0029 | .0232 | .0030 |
| Railroads and rail express service | | —.0504 | —.0385 | —.0345 | —.0385 | —.0408 | —.0714 | —.0174 | —.0263 |

**Table 1.14** (continued)

| Industry | 1948–1966 (average annual rates of growth) BLS | Kendrick | Translog | Translog Index of Labor Input (average annual rates of growth) 1947–1973 | 1947–1953 | 1953–1957 | 1957–1960 | 1960–1966 | 1966–1973 |
|---|---|---|---|---|---|---|---|---|---|
| Street rail., bus lines, and taxicabs | | | —.0200 | —.0183 | —.0241 | —.0325 | —.0186 | —.0119 | —.0106 |
| Trucking services and warehousing | | | .0316 | .0299 | .0456 | .0184 | .0192 | .0335 | .0245 |
| Water transportation | | —.0052 | —.0047 | .0078 | .0673 | .0070 | —.0355 | .0096 | —.0256 |
| Air transportation | | .0574 | .0587 | .0563 | .0638 | .0851 | .0439 | .0461 | .0475 |
| Pipelines ex. natural gas | | —.0281 | —.0185 | —.0131 | .0102 | —.0074 | —.0303 | —.0334 | —.0115 |
| Transportation services | | | .0188 | .0215 | .0117 | —.0149 | .0139 | .0468 | .0321 |
| Telephone, telegraph, misc. comm. services | | .0105 | .0187 | .0251 | .0314 | .0288 | —.0085 | .0226 | .0341 |
| Radio broadcasting and television | | | .0451 | .0472 | .0801 | .0410 | .0305 | .0341 | .0410 |
| Electric utilities | | | .0092 | .0169 | .0128 | .0318 | .0006 | .0085 | .0263 |
| Gas utilities | | | .0252 | .0259 | .0491 | .0009 | .0462 | .0153 | .0206 |
| Water supply and sanitary services | | | 0.133 | .0157 | .0271 | .0048 | —.0019 | .0203 | .0157 |
| Wholesale trade | .0175 | .0161 | .0202 | .0207 | .0161 | .0136 | .0278 | .0245 | .0223 |
| Retail trade | .0142 | .0095 | .0086 | .0094 | .0056 | .0012 | .0145 | .0077 | .0167 |
| Finance, insurance, and real estate | | .0270 | .0347 | .0358 | .0418 | .0323 | .0395 | .0288 | .0372 |
| Services, excl. priv. households and institutions | | | .0295 | .0294 | .0190 | .0279 | .0364 | .0346 | .0319 |
| Private households | | | —.0152 | —.0168 | —.0218 | .0067 | —.0003 | —.0285 | —.0230 |

**Table 1.14** (continued)

| Industry | 1948–1966 (average annual rates of growth) | | | Translog Index of Labor Input (average annual rates of growth) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | BLS | Kendrick | Translog | 1947–1973 | 1947–1953 | 1953–1957 | 1957–1960 | 1960–1966 | 1966–1973 |
| Institutions | | | .0476 | .0416 | .0436 | .0385 | .0852 | .0419 | .0227 |
| Federal public administration | | | .0239 | .0172 | .0443 | —.0060 | .0055 | .0280 | .0029 |
| Federal government enterprises | | | .0222 | .0198 | .0336 | .0091 | .0286 | .0227 | .0079 |
| State and local educ. services | | | .0562 | .0518 | .0522 | .0586 | .0628 | .0535 | .0413 |
| State and local public administration | | | .0392 | .0403 | .0472 | .0430 | .0270 | .0394 | .0394 |
| State and local govt. enterprises | | | .0360 | .0404 | .0783 | .0022 | .0647 | .0204 | .0364 |

sectors from the national product accounts. Similarly, we have controlled our data on property compensation by industry to totals from the national income accounts.

We have disaggregated the capital input of each industrial sector into cells cross-classified by six types of assets and three legal forms of organization listed in table 1.15. The classification by asset class corresponds to the breakdown of investment flows from the U.S. national product accounts. The classification by legal form of organization corresponds to the breakdown of property compensation from the U.S. national income accounts. Data on property compensation are available for forty-six of the fifty-one industry groups included in the list of industries presented in table 1.1 above. Data on property compensation for the five sectors corresponding to federal and state and local governments are not available. We have constructed indexes of capital input for the forty-six sectors of private industry for which data on property compensation are available. For two of these sectors—private households and nonprofit institutions—the legal form of organization is limited to households and institutions. The remaining forty-four sectors are divided between corporate and noncorporate business.

Our first task is to construct estimates of capital stock for each type of asset and each legal form of organization for forty-six sectors of private industry for each year for the period 1947–73. Consumers' durable equipment is used only by private households, while producers' durable equipment is used in every sector except private households. Residential structures are allocated between owner-occupied dwellings, assigned to the private household sector, and tenant-occupied dwellings, assigned to finance, insurance, and real estate. Nonresidential structures are assigned to every sector except private households. Inventories are employed in every sector except private households and nonprofit institutions. Land is employed in all forty-six sectors. For depreciable assets

**Table 1.15 Characteristics of Capital Input**

| | |
|---|---|
| Asset Class | |
| (1) | Producers' durable equipment |
| (2) | Consumers' durable equipment |
| (3) | Residential structures |
| (4) | Nonresidential structures |
| (5) | Inventories |
| (6) | Land |
| Legal Form | |
| (1) | Corporate business |
| (2) | Noncorporate business |
| (3) | Households and institutions |

—equipment and structures—we employ the perpetual inventory method to estimate capital stocks from data on investment. For inventories and land our estimates are based on balance-sheet data. We describe our data sources and the resulting estimates of capital stock in section 1.3.2.

Our second task is to construct estimates of rental prices by industrial sector for each type of asset and each legal form of organization for the period 1947–73. Our approach is based on the dual to the perpetual inventory method proposed and implemented by Christensen and Jorgenson (1969, 1973). The perpetual inventory method is based on the relationship between capital stock at a point of time and investment up to that point. The dual to the perpetual inventory method is based on the relationship between the price of an investment good at a point of time and rental prices of capital services from that point forward. Each rental price of capital services involves the nominal rate of return for the industrial sector, rates of depreciation and capital loss or gain for the type of asset, and variables incorporating the tax structure for the legal form of organization. We assume that the nominal rate of return after taxes is the same for all assets within a given sector and that the sum of rental payments for all assets is equal to total property compensation. On the basis of these assumptions we can allocate property compensation for each industry sector among types of assets and legal forms of organization. We describe our data sources and the resulting estimates of rental prices for capital services in section 1.3.3.

The desirability of disaggregating capital input by industrial sector, class of asset, and legal form of organization has been recognized by Christensen and Jorgenson (1969), Denison (1972), Griliches and Jorgenson (1966), Jorgenson and Griliches (1967, 1972), Kendrick (1973), and others. Kendrick has developed measures of capital input disaggregated by industry for much of the postwar period, but his measures do not incorporate a cross-classification by class of asset or legal form of organization. Denison has developed measures of capital input for the U.S. economy as a whole disaggregated by class of asset and by legal form of organization, but not by industry.

Data on capital input cross-classified by characteristics such as legal form of organization and industry are required for studies of capital demand and investment behavior; data cross-classified by asset class are required for studies of investment goods supply. Measures of capital input that fail to reflect differences in productivity among capital assets remain in common use. Kendrick's recent study of postwar productivity trends provides data on capital stock by industry; no attempt is made to construct measures of capital input that reflect differences in productivity among capital assets. We present indexes of capital input for the forty-six industry groups included in our study in section 1.3.4. Our data base can be used to generate indexes of capital input cross-classified by class of asset or legal form of organization for industrial sectors.

### 1.3.2 Capital Stock

We next describe the methodology and data sources employed in constructing estimates of capital stock by industry for each year for the period 1947–73. We construct estimates for each of the six asset classes and each of the three legal forms of organization listed in table 1.15. For equipment and structures we employ the perpetual inventory method,[29] assuming that replacement requirements follow a declining balance pattern for each asset, so that the relationship between investment and capital stock takes the form

$$A(T) = I(T) + (1-\delta)A(T-1),$$

where $\delta$ is the rate of replacement.

Jack Faucett Associates (1973*a*) has compiled annual time series data on investment by industrial sector for equipment and structures. These data are available for manufacturing industries through 1971 and for nonmanufacturing industries through 1970. The time series for equipment for each industry except nonprofit institutions begins in 1920 and covers investment in producers' durable equipment. We have employed estimates of investment in producers' durable equipment by nonprofit institutions from the Bureau of Economic Analysis *Capital Stock Study* (1976*a*).[30] Faucett's time series for structures for each industry except nonprofit institutions begins in 1890 and covers investment in nonresidential structures. The series for finance, insurance, and real estate also includes tenant-occupied residential structures. We have employed estimates of investment in nonresidential structures by nonprofit institutions and investment in owner-occupied residential structures by private households from the Bureau of Economic Analysis *Capital Stock Study*.

We have updated Faucett's investment series through 1972 for both manufacturing and nonmanufacturing industries. We have controlled the sum of investment for all sectors, including nonprofit institutions, for producers' durable equipment to total investment in producers' durables from the U.S. national product accounts for the period 1929–72 and to data from the *Capital Stock Study* for the period before 1929. Similarly, we have controlled the sum of investment in nonresidential structures for all sectors, including nonprofit institutions, to total investment in nonresidential structures from the U.S. national product accounts and the *Capital Stock Study*. Finally, we have controlled the sum

29. This account of the perpetual inventory method is based on that of Christensen and Jorgenson (1973), pp. 265–83; see also Jorgenson (1973).

30. See also Musgrave (1976).

of investment in residential structures for finance, insurance, and real estate and for private households to total investment in residential structures from the U.S. national product accounts and the *Capital Stock Study*.

The investment data compiled by Jack Faucett Associates are distributed among industrial sectors on an establishment basis. We have reallocated the investment data for nonmanufacturing industries so that the ratio of historical cost capital consumption allowances for the period 1947–73 to capital consumption allowances from the Bureau of Economic Analysis study of gross product originating is the same for all sectors. Finally, we have deflated the investment data from Jack Faucett Associates and the *Capital Stock Study* to obtain investment in constant prices; the deflators are based on investment goods prices from the U.S. national product accounts for the period 1929–72 and from the *Capital Stock Study* for the period before 1929.

Given time series data on investment in equipment and structures by industry, we have compiled estimates of capital stock by industry and by type of asset annually for the period 1947–73, expressing capital stock for each year as a weighted sum of past investments. We assume that the rate of replacement is twice the reciprocal of the lifetime of the corresponding asset for each industry from Jack Faucett Associates or the *Capital Stock Study*. This assumption results in double declining balance replacement patterns for all assets. Since the time series for investment in equipment begin in 1920 and our estimates of capital stock begin in 1947, we have set the level of investment for periods before 1920 equal to zero. Similarly, the time series for structures begin in 1890 and we have set the level of investment equal to zero before 1890. The final step in construction of our estimates of capital stock is to allocate stocks for each sector, except for private households and nonprofit institutions, between corporate and noncorporate business. We allocate stocks for each year in proportion to capital consumption allowances for corporate and for noncorporate business from the Bureau of Economic Analysis study of gross product originating.

Our construction of estimates of stocks of land begins with estimates of the value of land for the economy as a whole generated by Christensen and Jorgenson (1969, 1973). Christensen and Jorgenson based their estimates on the earlier studies of Goldsmith (1962) and Manvel (1968).

> To establish a benchmark for land we assume that land is 39 percent of the value of all private real estate in 1956. This is based on a study of the value of real estate and land by Manvel. Taking the value of residential and nonresidential structures in 1956 to be 61 percent of the value of all private real estate, we obtain a benchmark for the value of land in 1956. . . . We take the price index of land to be the

> same as Goldsmith's through 1958. We estimate the rate of growth of land prices between 1956 and 1966 to be 6.9 percent; we use this rate of growth to extrapolate Goldsmith's price index from 1958 to 1967 (in our case 1973).[31]

Using this price index, we estimated the market value of all private land annually for the period 1947–73. Following the procedure of Christensen and Jorgenson,[32] this current dollar aggregate was first allocated among sectors[33] using 1956 proportions from Manvel (1968). The land assigned to each sector was then allocated among legal forms of organization (corporate, noncorporate, and household) in proportion to data reported for 1956 by Goldsmith (1962). These data provided control totals for our estimates of land by industrial sector.

We employ balance sheet data from the IRS *Statistics of Income* (1974) to distribute the market value of land for the economy as a whole among industrial sectors. Fortunately, balance sheet data on book value of land by industrial sector are available for corporations for all years for the period 1947–73; however, the data are classified by industries defined on a company rather than establishment basis. The transformation of the balance sheet data to an establishment basis was accomplished by using the 1958 establishment-company ratios available in the Bureau of the Census *Enterprise Statistics* (1958). In addition, the *Statistics of Income* detail for nonmanufacturing industries is less than the industrial detail used throughout this study; the book value of land was distributed among subindustries using current dollar shares in total plant. Finally, the book values for each industry were adjusted proportionately so that their sum equaled the controlling market value total for corporate land. We assume that the ratio of market value to book value is constant across industries but not over time. Goldsmith's economy-wide index, extrapolated to the present by Christensen and Jorgenson, is employed as a land deflator for all industries. Dividing each industry's current dollar value of corporate land by this deflator, we obtain the quantity of land held by the corporate sector of each industry.

Noncorporate land data for partnerships and proprietorships are separately available from the *Statistics of Income* for only a limited number of years: four for partnerships and two for proprietorships. We began by generating a consistent set of industry data for each of the benchmark years (1953, 1959, 1963, and 1965) according to a method first suggested by Hulten (1973*b*):

31. Christensen and Jorgenson (1969), p. 296.

32. Ibid., p. 301.

33. The land aggregate for each year was distributed among farm, residential, and nonfarm nonresidential uses.

> (1) The *Statistics of Income* estimates are inflated from "partnership with balance sheets" to the level of "all partnerships" using the ratio of total receipts for the latter to total receipts for the former. (2) The resulting estimates are then adjusted to include sole proprietorships (to bring the estimates up to the noncorporate level). This is accomplished by calculating the ratio of total receipts of proprietorships and partnerships to total receipts of partnerships and using the result to inflate the partnership land estimates. (3) Data for missing industries are then estimated by allocating the total unaccounted-for land in the same proportion as the corresponding corporate book values. The result is a consistent set of benchmarks for the book values of noncorporate land.[34]

We then interpolated between and extrapolated beyond each industry's benchmark values using the book-value growth rates for the corporate land held by that sector. Dividing each current dollar industry series by our land deflator resulted in the desired series of quantities of land held by the noncorporate sector of each industry.

Sales and purchases of commodities held as inventories are frequently occurring events. This makes the estimation of current market values for inventory conceptually straightforward. The Bureau of Economic Analysis has constructed annual data on current and constant dollar inventory stocks by industry. Loftus and Hinrichs of the National Income and Wealth division kindly made available postwar time series of corporate and noncorporate inventory stocks and corresponding reflators[35] for twenty-one two-digit manufacturing sectors and nine nonmanufacturing aggregates. These estimates are consistent with establishment-basis industry definitions used throughout this research and, like all our other data series, are controlled to U.S. national income and product account totals. For the six nonmanufacturing sectors that require disaggregation,[36] we employ the stock distributions available from constant-dollar inventory stocks from *Measures of Working Capital* prepared by Jack Faucett Associates (1973*b*) and constant-dollar value added available for each industry from the Bureau of Economic Analysis (1974*a*).[37] We employ the inventory reflators for both corpo-

34. See Hulten (1973*b*), p. 67.

35. The reflators are the same for corporate and noncorporate stocks. For a discussion of the methodology underlying the construction of stocks of business inventories, see Loftus (1972).

36. These industries are agriculture, mining, transportation, communications and public utilities, finance and real estate, and services. The remaining three, construction and wholesale and retail trade, already had a one-to-one correspondence with our fifty-one-order list.

37. We assume that sectors within each industry aggregate, sharing similar technologies and product demand characteristics, have a common relation between inventories and value added.

rate and noncorporate stocks for all sectors included in each nonmanufacturing sector of the Bureau of Economic Analysis study.

### 1.3.3 Property Compensation

The dual to the perpetual inventory method originated by Christensen and Jorgenson (1969, 1973) provides the theoretical framework for our measures of the rental prices of capital services. For an asset with a declining pattern of replacement requirements, the rental price of capital services takes the form

$$p_K(T) = p_I(T-1)r(T) + \delta p_I(T) - [p_I(T) - p_I(T-1)].$$

The rental price is the sum of the nominal return to capital $p_I(T-1)$ $r(T)$ and depreciation $\delta p_I(T)$, less revaluation $p_I(T) - p_I(T-1)$. We can also express the rental price of capital services in terms of the price of investment goods, the own rate of return on capital in period $T$,

$$r(T) - \frac{p_I(T) - p_I(T-1)}{p_I(T-1)},$$

and depreciation:

$$p_K(T) = p_I(T-1)\left[r(T) - \frac{p_I(T) - p_I(T-1)}{p_I(T-1)}\right] + \delta p_I(T).$$

In the absence of taxation the value of capital services is the product of the rental price and the level of capital stock at the end of the preceding period:

$$p_K(T) \cdot A(T-1) = \{p_I(T-1)r(T) + \delta p_I(T) - [p_I(T) - p_I(T-1)]\} \times A(T-1).$$

Given the level of capital stock, the price of investment goods, and the rate of replacement, the rate of return on capital is the only variable that remains to be determined in the rental price of capital services.

For a sector not subject to direct or indirect taxes on property income, the value of property compensation is equal to the value of capital services. We can solve for the rate of return, given data on property compensation for the sector:

$$r(T) = \frac{\text{property compensation} - \{\delta p_I(T) - [p_I(T) - p_I(T-1)]\}A(T-1)}{p_I(T-1)A(T-1)}.$$

The rate of return is the ratio of property compensation less depreciation and plus capital gains to the value of assets at the beginning of the period. For a sector with more than one type of asset the value of property compensation is equal to the sum of the values of capital services over all assets. We assume that the rate of return is the same for all assets, so that we can solve for the rate of return as the ratio of property compensation for the sector less depreciation and plus capital gains for all assets to the value of all assets at the beginning of the period.

We have constructed estimates of capital stock by industry, cross-classified by the three legal forms of organization and six types of assets listed in table 1.15. Private households and nonprofit institutions are treated as separate sectors; capital stocks for the remaining forty-four industrial sectors are divided between noncorporate and corporate business. In measuring rates of return employed in our estimates of rental prices of capital services we must take into account differences in the tax treatment of property compensation among legal forms of organization. Households and institutions are not subject to direct taxes, but they are subject to property taxes. Noncorporate business is subject to direct taxation through the personal income tax. Corporate business is subject to both personal and corporate income taxes. Both noncorporate and corporate businesses are also subject to property taxes.

We can modify our expression for the rental price of capital services to incorporate property taxes by adding the rate of taxation, say $\tau(T)$, multiplied by the price of investment goods, to the rental price:

$$p_K(T) = p_I(T-1)r(T) + \delta p_I(T) - [p_I(T) - p_I(T-1)] + p_I(T)\tau(T).$$

To estimate the rate of return we set property compensation equal to the value of capital services, as before. The rate of return is the ratio of property compensation less depreciation, plus capital gains, and less property taxes, to the value of assets at the beginning of the period. Depreciation, capital gains, property taxes, and the value of assets are sums over all assets for a sector with more than one type of asset.

In measuring the value of capital services for private households and nonprofit institutions we first derive the value of services of owner-occupied residential real estate, including both land and residential structures, from data on the value of the use of dwellings in the U.S. national income and product accounts. To obtain the rate of return on capital we take the ratio of the value of the services of owner-occupied residential real estate less depreciation, plus capital gains, and less property taxes to the value of land and residential structures at the beginning of the period. We assume that the rate of return for consumers' durable equipment in private households and for all assets in nonprofit institutions—producers' durable equipment, nonresidential structures, and land—is the same as for owner-occupied residential real estate. Given the prices of each of these investment goods, rates of replacement for equipment and structures, and tax rates, we can determine the rental price of each type of asset utilized by private households and nonprofit institutions. Rates of replacement and the prices of investment goods are taken from those employed in construction of our estimates of capital stock, as described above. Effective rates of tax are equal to property taxes on each type of asset given in the U.S. national income and product accounts.

For each of the industrial sectors listed in table 1.1, excluding the five government sectors, private households, and nonprofit institutions, property compensation is defined on the basis of data included in the Bureau of Economic Analysis study of gross product originating. Property compensation for corporate business is defined as follows:

Corporate property compensation
= corporate capital consumption allowances
+ corporate business transfer payments
+ corporate business property and other taxes
+ corporate profits before tax
+ corporate inventory valuation adjustment
+ corporate net interest paid.

Property compensation for noncorporate business is defined as follows:

Noncorporate property compensation
= noncorporate capital consumption allowances
+ noncorporate business transfer payments
+ noncorporate business property and other taxes
+ income of unincorporated enterprises
— labor compensation of self-employed and unpaid family workers
+ rental income of persons
+ noncorporate inventory valuation adjustment
+ noncorporate net interest paid.

To estimate rental prices for the corporate sector of each industry we must take the taxation of corporate income into account. For producers' durable equipment the rental price of capital services, modified to take the corporate income tax and indirect business taxes into account, takes the form

$$p_K(T) = \left[\frac{1 - u(T)z(T) - k(T) + y(T)}{1 - u(T)}\right] \times \{p_I(T-1)r(T) + \delta p_I(T) - [p_I(T) - p_I(T-1)]\} + p_I(T)\tau(T),$$

where $u(T)$ is the corporate income tax rate, $z(T)$ is the present value of capital consumption allowances on one dollar's worth of investment, $k(T)$ is the rate of the investment tax credit, and $y(T)$ is a variable used in accounting for the fact that the investment credit was deducted from the value of an asset in calculating depreciation for tax purposes in 1962 and 1963:

$$\begin{aligned} y(T) &= k(T)u(T)z(T), \qquad && (T = 1962, 1963), \\ &= 0, && (T \neq 1962, 1963). \end{aligned}$$

For residential and nonresidential structures the rental price of capital services is the same as for producers' durable equipment, except that the rate of the investment tax credit $k(T)$ is equal to zero. For inventories and land the rate of replacement $\delta$, the present value of capital consumption allowances $z(T)$, and the rate of investment tax credit $k(T)$ are all equal to zero.

We estimate the effective rate of indirect taxation $\tau(T)$ for the corporate sector of each industry as the ratio of corporate business property and other taxes to the value of all corporate assets at the beginning of the period. We measure the effective rate of the corporate income tax $u(T)$ for each industry as the ratio of corporate tax liabilities plus the investment tax credit to corporate property compensation less corporate business property and other taxes and less the imputed value of capital consumption allowances for tax purposes. Imputed capital consumption differs from capital consumption allowances actually claimed for tax purposes in reflecting the present value of future capital consumption allowances; the present value depends on the depreciation formulas and lifetimes of assets allowed for tax purposes and the rate of return. We assume that the rate of return used in discounting future capital consumption allowances in the corporate sector is constant at 10%

In January 1973, the Treasury Department initiated a survey to determine the use and effectiveness of its then recently introduced Accelerated Depreciation Range system.

> The Asset Depreciation Range (ADR) initiated on March 12, 1971, provides a range of asset lives for various classes of assets placed in service after December 31, 1971. A taxpayer may elect to base the tax depreciation of an asset on any number of years within the designated range of years allowable for the particular guideline class of the asset . . . . The designated range for each class allows a minimum asset life 20% below and a maximum life 20% above the "Guideline" lives previously in effect.[38]

38. See Vasquez (1974), p. 2.

As useful by-products of this Treasury study, the Office of Tax Analysis compiled a detailed table of the 1970 (pre–ADR) and 1971 (ADR) equipment tax lives reported by both ADR electors and nonelectors within each of thirty-six industries. A similar table reporting separate percentage distributions over the various depreciation methods used by electors and nonelectors in 1971 was also produced. The four major depreciation formulas covered in the survey were straight-line, 1.5 declining balance, 2.0 declining balance, and sum-of-years digits. In addition, the Treasury report by Vasquez (1974) compares the depreciation methods and asset lives used by corporate taxpayers during 1954, 1954–59, 1970 (pre–ADR), and 1971 (ADR).[39] Given these Treasury data, we have constructed an annual time series of depreciation methods and tax lives for each of our forty-six industrial sectors.

Before 1954, taxpayers were limited to the straight-line method. We therefore imposed this depreciation pattern on each of our sectors. In 1954 depreciation allowances were liberalized to allow accelerated depreciation. Declining balance methods at twice the straight-line rate as well as the sum-of-years digits method were introduced. The Treasury report presents the average percentage use of these principal methods for the period immediately following the 1954 tax law change (1954–59) for eight industry aggregates. We moved these average distributions over the six-year period using annual manufacturing and nonmanufacturing data compiled and published by Young (1968).[40] Given the absence of industry detail in the Vasquez report, we assumed that the distribution of depreciation methods was identical for each industry within each of Vasquez's eight aggregates. A similar procedure was employed to interpolate the distributions of depreciation methods between the 1959 breakdowns and those presented by the Office of Tax Analysis (1973) for 1971. The 1971 data were then extrapolated to yield 1972 and 1973 distributions. The estimation of tax lives for equipment followed similar lines. Young (1968) prepared a set of economy-wide equipment tax life changes over the years prior to 1954.[41] We were able to use these to move the 1954 lives for ten industries reported by Vasquez[42] back to 1947. Once again, tax lives for all industries within each aggregate were assumed to move in the same proportion. Vasquez's 1954–59 averages were again moved in proportion to Young's estimates to levels given by the Treasury for thirty-six industries for 1970. Data for 1971 were also available from the Treasury and were extrapolated to produce 1972 and 1973 estimates.

39. See Vasquez (1974), pp. 34–37.
40. See Young (1968), p. 19.
41. See Young (1968), p. 20. We used his recommended "approximation I."
42. See Vasquez (1974), p. 37.

Since the ADR system applies only to investment in producers' durables, the Treasury study did not include an analysis of depreciation practices for structures. As a result, the only source of information on tax lives and methods of depreciation now available is based on the work of Young (1968). Young presents the distribution of depreciation methods for total manufacturing and nonmanufacturing for each year from 1954 to 1959 and an average for the period 1960–66.[43] We applied these estimates to each industry. The 1960–66 average was extrapolated through 1973. For tax service lives in 1945, 1950, 1952, 1955, 1957, 1960, 1961, and the 1962–66 period, Young presents economy-wide estimates of each year's percentage relationship to the average service life for structures purchased in 1940. Combining this time series with the Christensen-Jorgenson (1969) estimate of the lifetime for structures in 1953 (35.3 years),[44] we were able to convert Young's index to lifetimes. We then interpolated and extrapolated this series to generate estimates for the full 1947–73 period, applying the series to data on corporate structures in each industry.

Given data on depreciation methods and tax lives for structures and equipment, we estimated the present value of capital consumption allowances $z(T)$ for each asset as a weighted average of the present values for each depreciation method. The weights are the corporate investment shares in total corporate investment for the industry by firms using straight-line, 1.5 declining balance, 2.0 declining balance, and sum-of-years digits methods. The formulas for calculating that year's discounted present value of depreciation expenses according to the relevant depreciation methods are given by Hall and Jorgenson (1967, 1971); we adjusted these formulas to take into account the "half-year convention," permitting six months' depreciation to be taken for tax purposes during the year of acquisition.

Since Young (1968) distinguishes between straight-line and all accelerated methods for corporate structures, we used the double declining balance formula for all accelerated methods applied to corporate structures; second, since the Treasury report distinguishes between the depreciation practices of ADR electors and nonelectors in 1970 and 1971, each of the components of present value was divided between these two categories of taxpayers for 1970–73. Assuming that the after-tax rates of return are the same for all assets within each industry, corporate property compensation was set equal to the sum of rental payments for all types of capital services—equipment, structures, land, and inventories—in order to determine the rate of return after corporate income

43. See Young (1968), pp. 19–21. Prior to 1954 only the straight-line method was allowed.

44. See Christensen and Jorgenson (1969), p. 311.

taxes. Given the rate of return for each industry, the prices of capital goods, rates of replacement for equipment and structures for each industry, variables describing the corporate tax structure—$u(T)$, $z(T)$, $k(T)$—and the rate of property taxes, $\tau(T)$, for each industry, we can determine the rental price of each type of asset utilized by the corporate sector of each industry.

Our approach to the estimation of rental prices for each type of asset utilized by the noncorporate sector of each industry is similar to that for the corporate sector. We set all variables describing the corporate tax structure equal to zero. We estimate the effective rate of indirect taxation $\tau(T)$ for the noncorporate sector of each industry as the ratio of noncorporate business property and other taxes to the value of all noncorporate assets at the beginning of the period. We assume that the noncorporate rate of return is equal to the corporate rate of return after corporate taxes. Given the noncorporate rate of return for each industry, prices of investment goods, rates of replacement for each industry, and the noncorporate rate of property taxes for each industry, we can determine the rental price of each type of asset by industry. Noncorporate property compensation is equal to the sum of rental payments for all types of capital services—equipment, structures, land, and inventories. Labor compensation of self-employed and unpaid family workers is equal to the difference between all the components of noncorporate property compensation listed above, including income of unincorporated enterprises, and the sum of rental payments.

### 1.3.4 Indexes of Capital Input

We have outlined the development of data on capital stock and the rental price of capital services for each industrial sector, cross-classified by asset class and legal form of organization. To construct an index of capital input for each industrial sector we assume that sectoral capital input, say $\{K_i\}$, can be expressed as a translog function of its individual components, say $\{K_{ki}\}$. The corresponding index of sectoral capital input is a translog quantity index of individual capital inputs:

$$\ln K_i(T) - \ln K_i(T-1) = \Sigma \bar{v}^i_{Kk}[\ln K_{ki}(T) - \ln K_{ki}(T-1)], \qquad (i = 1, 2, \ldots, n),$$

where weights are given by average shares of each component in the value of sectoral property compensation:

$$\bar{v}^i_{Kk} = \frac{1}{2}[v^i_{Kk}(T) + v^i_{Kk}(T-1)], \qquad (i = 1, 2, \ldots, n; k = 1, 2, \ldots, p),$$

and

$$v^i_{Kk} = \frac{p^i_{Kk} K_{ki}}{\sum p^i_{Kk} K_{ki}},$$

$$(i = 1, 2, \ldots, n; k = 1, 2, \ldots, p).$$

The value shares are computed from data on capital services $\{K_{ki}\}$ and the rental price of capital services $\{p^i_{Kk}\}$ for each component of sectoral capital input, cross-classified by asset class and legal form of organization. Property compensation for the sector as a whole $\sum p^i_{Kk}K_{ki}$ is controlled to property compensation by industry from the U.S. national income accounts.

For each of the components of capital input into an industrial sector $\{K_{ki}(T)\}$ the flow of capital services is proportional to capital stock, say $\{A_{ki}(T-1)\}$:

$$K_{ki}(T) = Q^i_{Kk} A_{ki}(T-1),$$

$$(i = 1, 2, \ldots, n; k = 1, 2, \ldots, p),$$

where the constants of proportionality $\{Q^i_{Kk}\}$ transform capital stock into a flow of capital services. The translog quantity indexes of sectoral capital input $\{K_i\}$ can be expressed in terms of their components $\{K_{ki}\}$ or in terms of the components of sectoral capital stock $\{A_{ki}\}$:

$$\begin{aligned}\ln K_i(T) - \ln K_i(T-1) &= \sum \bar{v}^i_{Kk}[\ln K_{ki}(T) \\ &\quad - \ln K_{ki}(T-1)] \\ &= \sum \bar{v}^i_{Kk}[\ln A_{ki}(T-1) - \ln A_{ki}(T-2)],\end{aligned}$$

$$(i = 1, 2, \ldots, n).$$

We form sectoral indexes of capital input from data on capital stock by industry, cross-classified by asset class and legal form of organization. Changes in the logarithms of capital stock for each component are weighted by average shares in sectoral property compensation.

We can define sectoral capital stock, say $\{A_i(T-1)\}$, as the unweighted sum of its components:

$$A_i(T-1) = \sum A_{ki}(T-1), \qquad (i = 1, 2, \ldots, n).$$

Similarly, we can define *sectoral indexes of the quality of capital stock*, say $Q^i_K(T)$, that transform sectoral measures of capital stock into the translog indexes of capital input:

$$K_i(T) = Q^i_K(T) \cdot A_i(T-1), \qquad (i = 1, 2, \ldots n).$$

The sectoral indexes of the quality of capital stock can be expressed in the form

$$\ln Q^i_K(T) - \ln Q^i_K(T-1)$$
$$= \sum \bar{v}^i_K[\ln A_{ki}(T-1) - \ln A_{ki}(T-2)]$$
$$- [\ln A_i(T-1) - \ln A_i(T-2],$$
$$(i = 1, 2, \ldots, n),$$

so that these indexes reflect changes in the composition of capital stock within each sector. Sectoral capital quality remains unchanged if all components of capital stock within a sector are growing at the same rate. Sectoral quality rises if components with higher flows of capital input per unit of capital stock are growing more rapidly and falls if components with lower flows are growing more rapidly.

We have generated translog indexes of capital input for the forty-six industries in the private domestic sector of the U.S. economy listed in table 1.1. Based on the capital stock and property compensation data described above, translog indexes of capital input for the private domestic economy and for a number of sectoral divisions are presented in column (4) of tables 1.16 through 1.26. Unweighted indexes of capital stock based on the same data are given in column (2). The ratio between these series, presented in column (3), measures the change in capital quality. To facilitate comparisons with unweighted and industry-weighted capital stock indexes, industry series employed by Kendrick are presented in columns (1) and (5). These capital indexes have been taken directly from his *Postwar Productivity Trends in the United States: 1948–1969* (1973). A comparison of rates of growth in Kendrick with translog indexes of capital input over the 1948–66 period is presented for all forty-six industries in table 1.27. In addition, rates of growth of the translog indexes of sectoral capital input are presented for five subperiods of the period 1947–73. Rates of growth of capital input for the period as a whole are also reported in table 1.27.

## 1.4 Output, Intermediate Input, and Productivity

### 1.4.1 Introduction

One of the principal features that distinguishes our approach to productivity from its predecessors is the definition of output at the sectoral level. At the economy-wide level the appropriate definition of output is based on deliveries to final demand—consumption, investment, government, and net exports. The corresponding definition of input is based on value added by primary factors of production—capital and labor input. The value of output is equal to the value of capital and labor input. At the sectoral level capital and labor input are combined with inputs of intermediate goods to produce output, so that the value of

**Table 1.16 Private Domestic Economy (1972=1.000)**

| Year | Capital Stock: Kendrick (1) | Capital Stock: Translog (2) | Capital Quality (3) | Capital Input: Translog (4) | Capital Input: Kendrick (5) |
|---|---|---|---|---|---|
| 1947 | .435 | .446 | .715 | .319 | .392 |
| 1948 | .451 | .470 | .742 | .349 | .407 |
| 1949 | .470 | .485 | .774 | .375 | .423 |
| 1950 | .489 | .513 | .764 | .392 | .437 |
| 1951 | .514 | .536 | .787 | .422 | .461 |
| 1952 | .535 | .552 | .814 | .450 | .485 |
| 1953 | .554 | .569 | .819 | .466 | .503 |
| 1954 | .572 | .584 | .831 | .485 | .519 |
| 1955 | .594 | .609 | .822 | .501 | .536 |
| 1956 | .618 | .631 | .842 | .531 | .560 |
| 1957 | .639 | .647 | .858 | .556 | .581 |
| 1958 | .653 | .657 | .877 | .576 | .592 |
| 1959 | .671 | .675 | .869 | .587 | .606 |
| 1960 | .691 | .692 | .877 | .607 | .624 |
| 1961 | .707 | .706 | .889 | .627 | .638 |
| 1962 | .724 | .725 | .886 | .642 | .653 |
| 1963 | .744 | .747 | .892 | .666 | .671 |
| 1964 | .766 | .771 | .897 | .691 | .694 |
| 1965 | .796 | .801 | .898 | .720 | .722 |
| 1966 | .835 | .835 | .913 | .762 | .762 |
| 1967 | | .862 | .939 | .809 | |
| 1968 | | .891 | .950 | .847 | |
| 1969 | | .921 | .965 | .888 | |
| 1970 | | .942 | .991 | .933 | |
| 1971 | | .967 | .996 | .963 | |
| 1972 | | 1.000 | 1.000 | 1.000 | |
| 1973 | | 1.037 | 1.015 | 1.053 | |

**Table 1.17** **Agriculture (1972=1.000)**

| Year | Capital Stock | | Capital Quality | Capital Input | |
|---|---|---|---|---|---|
| | Kendrick (1) | Translog (2) | (3) | Translog (4) | Kendrick (5) |
| 1947 | | .628 | .775 | .487 | .706 |
| 1948 | | .675 | .759 | .512 | .719 |
| 1949 | | .685 | .810 | .555 | .736 |
| 1950 | | .712 | .795 | .566 | .751 |
| 1951 | | .740 | .820 | .607 | .769 |
| 1952 | | .767 | .828 | .635 | .782 |
| 1953 | | .773 | .862 | .666 | .789 |
| 1954 | | .785 | .866 | .680 | .794 |
| 1955 | | .800 | .864 | .691 | .798 |
| 1956 | | .781 | .907 | .708 | .796 |
| 1957 | | .794 | .874 | .694 | .794 |
| 1958 | | .812 | .853 | .693 | .794 |
| 1959 | | .811 | .874 | .709 | .796 |
| 1960 | | .818 | .877 | .718 | .798 |
| 1961 | | .817 | .880 | .718 | .798 |
| 1962 | | .834 | .867 | .723 | .802 |
| 1963 | | .860 | .856 | .736 | .807 |
| 1964 | | .862 | .884 | .762 | .809 |
| 1965 | | .879 | .886 | .779 | .810 |
| 1966 | | .928 | .876 | .813 | .813 |
| 1967 | | .932 | .915 | .853 | |
| 1968 | | .964 | .920 | .887 | |
| 1969 | | 1.024 | .893 | .915 | |
| 1970 | | 1.035 | .915 | .947 | |
| 1971 | | 1.054 | .922 | .971 | |
| 1972 | | 1.000 | 1.000 | 1.000 | |
| 1973 | | 1.038 | .944 | .980 | |

Table 1.18 **Mining (1972=1.000)**

| Year | Capital Stock: Kendrick (1) | Capital Stock: Translog (2) | Capital Quality (3) | Capital Input: Translog (4) | Capital Input: Kendrick (5) |
|---|---|---|---|---|---|
| 1947 | | .626 | .850 | .532 | |
| 1948 | | .643 | .906 | .583 | 1.080 |
| 1949 | | .640 | .949 | .607 | |
| 1950 | | .644 | .946 | .609 | |
| 1951 | | .650 | .949 | .617 | |
| 1952 | | .668 | .937 | .627 | |
| 1953 | | .676 | .965 | .652 | 1.060 |
| 1954 | | .684 | .968 | .662 | |
| 1955 | | .725 | .922 | .669 | |
| 1956 | | .743 | .969 | .720 | |
| 1957 | | .765 | .959 | .734 | 1.081 |
| 1958 | | .776 | .969 | .752 | |
| 1959 | | .798 | .966 | .771 | |
| 1960 | | .820 | .973 | .798 | 1.113 |
| 1961 | | .854 | .963 | .822 | |
| 1962 | | .866 | .984 | .852 | |
| 1963 | | .869 | .999 | .869 | |
| 1964 | | .901 | .973 | .877 | |
| 1965 | | .918 | .994 | .913 | |
| 1966 | | .933 | 1.000 | .933 | .933 |
| 1967 | | .939 | 1.023 | .961 | |
| 1968 | | .939 | 1.028 | .965 | |
| 1969 | | .951 | 1.022 | .972 | |
| 1970 | | .956 | 1.028 | .982 | |
| 1971 | | .964 | 1.026 | .989 | |
| 1972 | | 1.000 | 1.000 | 1.000 | |
| 1973 | | 1.014 | 1.024 | 1.038 | |

**Table 1.19 Contract Construction (1972=1.000)**

| Year | Capital Stock | | Capital Quality | Capital Input | |
|---|---|---|---|---|---|
| | Kendrick (1) | Translog (2) | (3) | Translog (4) | Kendrick (5) |
| 1947 | | .158 | .925 | .146 | |
| 1948 | | .173 | 1.032 | .178 | .223 |
| 1949 | | .184 | 1.064 | .196 | .259 |
| 1950 | | .222 | .940 | .209 | .270 |
| 1951 | | .254 | .982 | .250 | .315 |
| 1952 | | .286 | .989 | .283 | .346 |
| 1953 | | .282 | 1.127 | .318 | .352 |
| 1954 | | .314 | 1.003 | .315 | .353 |
| 1955 | | .341 | 1.018 | .347 | .359 |
| 1956 | | .371 | 1.028 | .381 | .390 |
| 1957 | | .405 | 1.014 | .411 | .434 |
| 1958 | | .429 | 1.051 | .451 | .462 |
| 1959 | | .472 | 1.002 | .473 | .480 |
| 1960 | | .494 | 1.055 | .521 | .507 |
| 1961 | | .541 | 1.002 | .542 | .535 |
| 1962 | | .574 | 1.003 | .576 | .568 |
| 1963 | | .614 | 1.001 | .614 | .612 |
| 1964 | | .661 | 1.003 | .663 | .661 |
| 1965 | | .718 | .991 | .712 | .714 |
| 1966 | | .758 | 1.019 | .772 | .772 |
| 1967 | | .820 | 1.004 | .823 | |
| 1968 | | .826 | 1.062 | .877 | |
| 1969 | | .852 | 1.052 | .896 | |
| 1970 | | .890 | 1.048 | .932 | |
| 1971 | | .915 | 1.062 | .971 | |
| 1972 | | 1.000 | 1.000 | 1.000 | |
| 1973 | | 1.037 | 1.039 | 1.077 | |

**Table 1.20 Manufacturing (1972=1.000)**

| Year | Capital Stock | | Capital Quality | Capital Input | |
|---|---|---|---|---|---|
| | Kendrick (1) | Translog (2) | (3) | Translog (4) | Kendrick (5) |
| 1947 | .429 | .475 | .811 | .385 | |
| 1948 | .452 | .493 | .856 | .422 | .404 |
| 1949 | .469 | .491 | .902 | .442 | .415 |
| 1950 | .480 | .506 | .867 | .438 | .417 |
| 1951 | .515 | .552 | .818 | .451 | .443 |
| 1952 | .554 | .570 | .877 | .500 | .484 |
| 1953 | .579 | .588 | .885 | .521 | .502 |
| 1954 | .591 | .590 | .914 | .539 | .505 |
| 1955 | .602 | .610 | .893 | .545 | .508 |
| 1956 | .631 | .644 | .889 | .573 | .538 |
| 1957 | .658 | .658 | .926 | .609 | .558 |
| 1958 | .665 | .654 | .960 | .628 | .566 |
| 1959 | .671 | .657 | .955 | .627 | .575 |
| 1960 | .685 | .669 | .950 | .635 | .587 |
| 1961 | .694 | .678 | .953 | .646 | .593 |
| 1962 | .707 | .694 | .947 | .657 | .603 |
| 1963 | .722 | .706 | .958 | .676 | .628 |
| 1964 | .742 | .731 | .947 | .693 | .654 |
| 1965 | .776 | .770 | .941 | .724 | .698 |
| 1966 | .833 | .833 | .926 | .771 | .771 |
| 1967 | | .890 | .942 | .838 | |
| 1968 | | .926 | .961 | .889 | |
| 1969 | | .957 | .969 | .928 | |
| 1970 | | .981 | .988 | .969 | |
| 1971 | | .985 | 1.008 | .993 | |
| 1972 | | 1.000 | 1.000 | 1.000 | |
| 1973 | | 1.028 | .996 | 1.024 | |

Table 1.21 **Transportation (1972=1.000)**

| Year | Capital Stock | | Capital Quality | Capital Input | |
|---|---|---|---|---|---|
| | Kendrick (1) | Translog (2) | (3) | Translog (4) | Kendrick (5) |
| 1947 | | .664 | .723 | .480 | |
| 1948 | | .650 | .808 | .525 | .564 |
| 1949 | | .634 | .829 | .525 | .580 |
| 1950 | | .628 | .825 | .519 | .593 |
| 1951 | | .621 | .847 | .527 | .609 |
| 1952 | | .625 | .840 | .524 | .626 |
| 1953 | | .634 | .842 | .533 | .640 |
| 1954 | | .621 | .879 | .546 | .651 |
| 1955 | | .625 | .870 | .544 | .660 |
| 1956 | | .622 | .893 | .556 | .669 |
| 1957 | | .629 | .883 | .555 | .679 |
| 1958 | | .625 | .913 | .570 | .686 |
| 1959 | | .653 | .873 | .570 | .690 |
| 1960 | | .665 | .922 | .613 | .697 |
| 1961 | | .669 | .941 | .629 | .701 |
| 1962 | | .691 | .919 | .635 | .706 |
| 1963 | | .701 | .955 | .669 | .712 |
| 1964 | | .722 | .942 | .680 | .720 |
| 1965 | | .760 | .928 | .706 | .735 |
| 1966 | | .806 | .940 | .758 | .758 |
| 1967 | | .842 | .969 | .816 | |
| 1968 | | .888 | .967 | .858 | |
| 1969 | | .936 | .969 | .907 | |
| 1970 | | .969 | .990 | .959 | |
| 1971 | | .985 | 1.000 | .985 | |
| 1972 | | 1.000 | 1.000 | 1.000 | |
| 1973 | | 1.019 | .998 | 1.017 | |

**Table 1.22 Communications and Public Utilities (1972 = 1.000)**

| Year | Capital Stock | | Capital Quality | Capital Input | |
|---|---|---|---|---|---|
| | Kendrick (1) | Translog (2) | (3) | Translog (4) | Kendrick (5) |
| 1947 | | .334 | .880 | .294 | |
| 1948 | | .345 | .895 | .308 | .244 |
| 1949 | | .353 | .921 | .325 | .268 |
| 1950 | | .359 | .945 | .339 | .289 |
| 1951 | | .363 | .962 | .349 | .310 |
| 1952 | | .388 | .914 | .355 | .332 |
| 1953 | | .399 | .960 | .383 | .356 |
| 1954 | | .401 | .996 | .400 | .379 |
| 1955 | | .408 | .996 | .407 | .401 |
| 1956 | | .420 | .994 | .417 | .422 |
| 1957 | | .442 | .971 | .429 | .450 |
| 1958 | | .461 | .989 | .456 | .484 |
| 1959 | | .475 | 1.008 | .479 | .504 |
| 1960 | | .495 | 1.001 | .495 | .530 |
| 1961 | | .511 | 1.021 | .522 | .550 |
| 1962 | | .529 | 1.020 | .539 | .567 |
| 1963 | | .557 | 1.008 | .561 | .586 |
| 1964 | | .586 | 1.017 | .596 | .609 |
| 1965 | | .619 | 1.019 | .630 | .634 |
| 1966 | | .653 | 1.024 | .669 | .669 |
| 1967 | | .691 | 1.026 | .709 | |
| 1968 | | .732 | 1.025 | .750 | |
| 1969 | | .789 | 1.009 | .797 | |
| 1970 | | .843 | 1.020 | .860 | |
| 1971 | | .915 | 1.007 | .922 | |
| 1972 | | 1.000 | 1.000 | 1.000 | |
| 1973 | | 1.104 | .990 | 1.092 | |

**Table 1.23** **Trade (1972=1.000)**

| Year | Capital Stock: Kendrick (1) | Capital Stock: Translog (2) | Capital Quality (3) | Capital Input: Translog (4) | Capital Input: Kendrick (5) |
|---|---|---|---|---|---|
| 1947 | | .320 | .812 | .260 | |
| 1948 | | .363 | .855 | .310 | .348 |
| 1949 | | .381 | .919 | .350 | .380 |
| 1950 | | .431 | .858 | .369 | .402 |
| 1951 | | .449 | .924 | .415 | .439 |
| 1952 | | .456 | .945 | .431 | .447 |
| 1953 | | .464 | .938 | .436 | .450 |
| 1954 | | .472 | .934 | .441 | .453 |
| 1955 | | .509 | .883 | .450 | .467 |
| 1956 | | .524 | .930 | .488 | .497 |
| 1957 | | .529 | .950 | .502 | .518 |
| 1958 | | .532 | .958 | .510 | .525 |
| 1959 | | .556 | .926 | .515 | .535 |
| 1960 | | .579 | .938 | .543 | .552 |
| 1961 | | .583 | .974 | .568 | .570 |
| 1962 | | .608 | .954 | .580 | .586 |
| 1963 | | .638 | .952 | .607 | .615 |
| 1964 | | .669 | .959 | .641 | .646 |
| 1965 | | .709 | .954 | .676 | .681 |
| 1966 | | .762 | .947 | .722 | .722 |
| 1967 | | .789 | .998 | .787 | |
| 1968 | | .827 | .995 | .823 | |
| 1969 | | .863 | 1.007 | .870 | |
| 1970 | | .895 | 1.022 | .915 | |
| 1971 | | .943 | 1.006 | .948 | |
| 1972 | | 1.000 | 1.000 | 1.000 | |
| 1973 | | 1.040 | 1.024 | 1.064 | |

Table 1.24 **Finance, Insurance, and Real Estate (1972=1.000)**

| Year | Capital Stock: Kendrick (1) | Capital Stock: Translog (2) | Capital Quality (3) | Capital Input: Translog (4) | Capital Input: Kendrick (5) |
|---|---|---|---|---|---|
| 1947 | | .689 | .566 | .390 | |
| 1948 | | .707 | .550 | .389 | |
| 1949 | | .716 | .582 | .417 | |
| 1950 | | .733 | .599 | .439 | |
| 1951 | | .751 | .629 | .473 | |
| 1952 | | .751 | .675 | .507 | |
| 1953 | | .766 | .660 | .506 | |
| 1954 | | .783 | .679 | .531 | |
| 1955 | | .794 | .709 | .563 | |
| 1956 | | .818 | .712 | .583 | |
| 1957 | | .833 | .748 | .623 | |
| 1958 | | .837 | .782 | .655 | |
| 1959 | | .846 | .782 | .661 | |
| 1960 | | .855 | .782 | .668 | |
| 1961 | | .867 | .800 | .693 | |
| 1962 | | .879 | .815 | .717 | |
| 1963 | | .891 | .836 | .745 | |
| 1964 | | .903 | .834 | .752 | |
| 1965 | | .920 | .807 | .743 | |
| 1966 | | .925 | .847 | .783 | |
| 1967 | | .938 | .860 | .807 | |
| 1968 | | .949 | .887 | .842 | |
| 1969 | | .958 | .915 | .877 | |
| 1970 | | .966 | .962 | .929 | |
| 1971 | | .980 | .980 | .960 | |
| 1972 | | 1.000 | 1.000 | 1.000 | |
| 1973 | | 1.020 | 1.056 | 1.077 | |

**Table 1.25** **Services, Excluding Private Households and Nonprofit Institutions and Including Government Enterprises (1972=1.000)**

| Year | Capital Stock | | Capital Quality | Capital Input | |
|---|---|---|---|---|---|
| | Kendrick (1) | Translog (2) | (3) | Translog (4) | Kendrick (5) |
| 1947 | | .499 | .907 | .452 | |
| 1948 | | .490 | .929 | .455 | |
| 1949 | | .481 | .933 | .448 | |
| 1950 | | .475 | .928 | .441 | |
| 1951 | | .466 | .929 | .433 | |
| 1952 | | .458 | .925 | .424 | |
| 1953 | | .453 | .914 | .414 | |
| 1954 | | .444 | .925 | .411 | |
| 1955 | | .455 | .880 | .401 | |
| 1956 | | .469 | .891 | .418 | |
| 1957 | | .483 | .901 | .435 | |
| 1958 | | .492 | .918 | .452 | |
| 1959 | | .523 | .889 | .466 | |
| 1960 | | .540 | .917 | .495 | |
| 1961 | | .568 | .921 | .523 | |
| 1962 | | .598 | .922 | .552 | |
| 1963 | | .639 | .917 | .586 | |
| 1964 | | .674 | .939 | .632 | |
| 1965 | | .715 | .941 | .673 | |
| 1966 | | .762 | .953 | .727 | |
| 1967 | | .783 | .999 | .782 | |
| 1968 | | .839 | .960 | .806 | |
| 1969 | | .899 | .975 | .877 | |
| 1970 | | .933 | 1.015 | .948 | |
| 1971 | | .958 | 1.017 | .975 | |
| 1972 | | 1.000 | 1.000 | 1.000 | |
| 1973 | | 1.055 | .989 | 1.044 | |

**Table 1.26** **Private Householders and Nonprofit Institutions (1972=1.000)**

| Year | Capital Stock: Kendrick (1) | Capital Stock: Translog (2) | Capital Quality (3) | Capital Input: Translog (4) | Capital Input: Kendrick (5) |
|---|---|---|---|---|---|
| 1947 | | .341 | .754 | .257 | |
| 1948 | | .368 | .774 | .285 | .372 |
| 1949 | | .394 | .796 | .314 | .380 |
| 1950 | | .431 | .796 | .343 | .392 |
| 1951 | | .457 | .847 | .387 | .405 |
| 1952 | | .478 | .866 | .414 | .417 |
| 1953 | | .501 | .865 | .434 | .429 |
| 1954 | | .525 | .874 | .459 | .443 |
| 1955 | | .558 | .864 | .482 | .460 |
| 1956 | | .583 | .891 | .520 | .477 |
| 1957 | | .604 | .905 | .546 | .498 |
| 1958 | | .619 | .917 | .568 | .521 |
| 1959 | | .644 | .903 | .582 | .545 |
| 1960 | | .665 | .913 | .607 | .571 |
| 1961 | | .680 | .923 | .628 | .597 |
| 1962 | | .701 | .916 | .643 | .625 |
| 1963 | | .727 | .916 | .666 | .653 |
| 1964 | | .755 | .921 | .695 | .685 |
| 1965 | | .787 | .927 | .729 | .726 |
| 1966 | | .817 | .943 | .770 | .770 |
| 1967 | | .843 | .963 | .812 | |
| 1968 | | .875 | .967 | .846 | |
| 1969 | | .904 | .984 | .889 | |
| 1970 | | .925 | 1.006 | .930 | |
| 1971 | | .956 | 1.002 | .959 | |
| 1972 | | 1.000 | 1.000 | 1.000 | |
| 1973 | | 1.043 | 1.013 | 1.057 | |

**Table 1.27 Capital Input: Rates of Growth**

| Industry | 1948–1966 (average annual rates of growth) Kendrick | Translog | Translog Index of Capital Input (average annual rates of growth) 1947–1973 | 1947–1953 | 1953–1957 | 1957–1960 | 1960–1966 | 1966–1973 |
|---|---|---|---|---|---|---|---|---|
| Agricultural production | | .0238 | .0248 | .0511 | .0088 | .0097 | .0180 | .0238 |
| Agricultural services | | .0685 | .0651 | .1077 | .0490 | .0444 | .0568 | .0540 |
| Metal mining | .0234 | .0878 | .0604 | .0743 | .0785 | .2175 | .0421 | −.0135 |
| Coal mining | −.0164 | .0281 | .0480 | .1378 | −.0653 | .0482 | .0453 | .0380 |
| Crude petroleum and natural gas | −.0237 | .0122 | .0102 | −.0042 | .0264 | .0057 | .0169 | .0095 |
| Nonmetallic mining and quarrying | .0472 | .1051 | .0979 | .1864 | .1030 | .0989 | .0745 | .0387 |
| Contract construction | .0691 | .0814 | .0768 | .1294 | .0643 | .0792 | .0655 | .0475 |
| Food and kindred products | | .0203 | .0237 | .0408 | .0138 | .0155 | .0208 | .0209 |
| Tobacco manufacturers | .0193 | .0156 | .0138 | .0297 | .0074 | .0120 | .0151 | .0034 |
| Textile mill products | .0007 | .0233 | .0320 | .0701 | .0064 | −.0355 | .0302 | .0446 |
| Apparel and other fabr. textile prod. | .0393 | .0279 | .0355 | .0383 | .0141 | .0044 | .0444 | .0510 |
| Paper and allied products | .0388 | .0499 | .0513 | .0767 | .0647 | .0376 | .0371 | .0398 |
| Printing and publishing | .0227 | −.0022 | .0078 | −.0155 | −.0125 | .0014 | .0168 | .0346 |
| Chemicals and allied products | .0514 | .0419 | .0453 | .0637 | .0384 | .0235 | .0441 | .0439 |
| Petroleum and coal products | .0302 | .0133 | .0179 | .0135 | .0421 | −.0026 | −.0018 | .0334 |
| Rubber and misc. plastic products | .0371 | .0046 | .0262 | −.0792 | .0548 | .0319 | .0585 | .0702 |
| Leather and leather products | .0028 | .0127 | .0155 | .0494 | .0077 | −.0243 | .0028 | .0190 |
| Lumber and wood prod. excluding furniture | .0192 | .0250 | .0319 | .0693 | .0320 | −.0113 | .0120 | .0354 |
| Furniture and fixtures | .0152 | .0248 | .0313 | .0299 | .0234 | .0174 | .0327 | .0416 |
| Stone, clay, and glass products | .0408 | .0439 | .0431 | .0705 | .0666 | .0409 | .0235 | .0238 |
| Primary metal industries | .0319 | .0242 | .0244 | .0341 | .0294 | .0197 | .0141 | .0239 |
| Fabricated metal industries | .0406 | .0367 | .0400 | .0562 | .0435 | .0182 | .0349 | .0380 |
| Machinery excluding electrical | .0278 | .0454 | .0505 | .0691 | .0462 | .0281 | .0431 | .0529 |

**Table 1.27** (continued)

| Industry | 1948–1966 (average annual rates of growth) | | Translog Index of Capital Input (average annual rates of growth) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Kendrick | Translog | 1947–1973 | 1947–1953 | 1953–1957 | 1957–1960 | 1960–1966 | 1966–1973 |
| Elec. machinery, eqpt., and supplies | .0626 | .0545 | .0575 | .0874 | .0553 | .0071 | .0555 | .0565 |
| Trans. eqpt. and ord. ex. motor vehicles | | −.0054 | .0160 | −.0349 | .0278 | −.0066 | .0160 | .0627 |
| Motor vehicles and equipment | | .0357 | .0355 | .0513 | .0638 | −.0222 | .0363 | .0300 |
| Prof. photographic eqpt. and watches | .0506 | .0714 | .0705 | .1144 | .0820 | .0336 | .0433 | .0654 |
| Misc. manufacturing industries | .0740 | .0215 | .0334 | .0140 | .0382 | .0076 | .0349 | .0569 |
| Railroads and rail express service | .0330 | −.0100 | −.0087 | −.0144 | −.0085 | −.0180 | −.0038 | −.0041 |
| Street rail., bus lines, and taxicabs | | −.0211 | −.0032 | −.0037 | −.0405 | −.0255 | .0011 | .0244 |
| Trucking services and warehousing | | .0696 | .0805 | .1343 | .0530 | .0816 | .0662 | .0620 |
| Water transportation | .0002 | −.0353 | −.0241 | −.0724 | −.0493 | −.0057 | −.0112 | .0127 |
| Air transportation | .0230 | .0992 | .0994 | .0435 | .0926 | .2034 | .1121 | .0956 |
| Pipelines ex. natural gas | .0772 | −.0109 | −.0055 | −.0036 | −.0203 | −.0412 | .0047 | .0079 |
| Transportation services | | .0205 | .0105 | −.0663 | .0204 | .0686 | .0642 | −.0001 |
| Telephone, telegraph, and misc. comm. services | .0598 | .0550 | .0678 | .0520 | .0331 | .0521 | .0872 | .0913 |
| Radio broadcasting and television | | .1194 | .1012 | .0886 | .2077 | .1039 | .1066 | .0455 |
| Electric utilities | | .0334 | .0411 | .0310 | .0355 | .0314 | .0294 | .0671 |
| Gas utilities | | .0276 | .0306 | .0678 | −.0218 | .0626 | .0112 | .0316 |
| Water supply and sanitary services | | .0486 | .0506 | .0266 | .0416 | .0689 | .0489 | .0700 |
| Wholesale trade | .0502 | .0527 | .0587 | .0928 | .0412 | .0274 | .0481 | .0619 |
| Retail trade | .0361 | .0433 | .0512 | .0815 | .0318 | .0253 | .0470 | .0510 |
| Finance, insurance, and real estate | | .0389 | .0391 | .0432 | .0520 | .0236 | .0264 | .0456 |
| Services, excl. priv. households and institutions | | .0260 | .0322 | −.0149 | .0128 | .0428 | .0639 | .0518 |
| Private households | | .0557 | .0552 | .0891 | .0585 | .0348 | .0391 | .0466 |
| Institutions | | .0426 | .0363 | .0356 | .0352 | .0414 | .0513 | .0224 |

output includes the value of intermediate input as well as the value of capital and labor input.

We define the value of output and input for each sector from the point of view of the producer. For each sector of the economy we measure revenue as proceeds to the sector and outlay as expenditures of the sector. The value of output includes the value of primary factor inputs, capital and labor, and the value of intermediate input. The value of output is net of indirect business taxes on output, sales and excise taxes, as well as all trade and transportation margins associated with deliveries of output to consuming sectors; the value of input includes all taxes on intermediate, capital, and labor input and all trade and transport costs incurred in taking delivery of intermediate input. In the preceding sections we have described our approach to the measurement of price and quantities of capital and labor input. In this section we turn our attention to the measurement of prices and quantities of output and intermediate input.

Consistent time series data on output in current and constant prices for the manufacturing industries listed in table 1.1 above are available from the Interindustry Economics Division of the Bureau of Economic Analysis (1974*b*). These data incorporate the value of shipments and the cost of goods sold from the *Annual Survey of Manufactures*. The data are based on industry definitions from the U.S. national income and product accounts. Jack Faucett Associates (1975) has developed data on output in current and constant prices for nonmanufacturing industries for two classifications of these industries—the 160-order Economic Growth Sectoring Plan of the Bureau of Labor Statistics and the 80-order sectoring of interindustry transactions by the Bureau of Economic Analysis. These classifications are far more detailed than the breakdown of nonmanufacturing industries given in table 1.1 above. However, the data are based on industry definitions employed in interindustry accounts rather than those used in the national income and product accounts.

For the twenty-one manufacturing industries listed in table 1.1, we have used the BEA data on output in current and constant prices. For twenty nonmanufacturing sectors, we have employed data on output in current and constant prices developed by Faucett, adjusted so as to conform with industry definitions used in the national income and product accounts. For the remaining ten nonmanufacturing sectors, our estimates of output in current and constant prices are derived from data provided by the Bureau of Economic Analysis (BEA). By comparing nonmanufacturing industry definitions used by Faucett, BEA, and BLS, we were able to identify the standard industrial classification (SIC) appropriate for each nonmanufacturing industry. To make our estimates conform with national accounting concepts, a number of adjustments are required. Principal among these are a reallocation of each sector's output of secondary products and a reconciliation of interindustry and national accounts industry definitions.

Activity redefinitions and SIC reclassifications account for the major differences between the interindustry and the national income and product accounts industry definitions. While the national accounts adhere strictly to SIC conventions, input-output sectors are defined so as to achieve more homogeneous product groupings. An example of an SIC reclassification initiated for interindustry accounts is the reallocation of veterinary services from the agricultural sector to the services sector; an example of interindustry activity redefinitions is the reallocation from the railroad to the construction sector of all construction and installation work performed by railroad employees in the railroad sector. With the aid of unpublished 80-order data on sectoral input provided by the Bureau of Economic Analysis,[45] we were able to reallocate the output associated with each interindustry activity redefinition and industry reclassification in Faucett's data to the appropriate national accounts sectors. This reconciled our industry definitions with those that underlie the national accounts.

A second adjustment required to make our estimates conform to national accounting conventions involves the reallocation of each sector's production of secondary products. In the national accounts all primary and secondary products are allocated to the sector in which they are produced. There are no transfers in or out. By contrast, the interindustry data follow the convention of transferring into each sector the goods that are secondary to other industries but primary to the receiving sector. "The secondary output is treated as if sold by the producing industry to the industry to which it is primary, and is added to the output of the primary industry for distribution to users."[46] Fortunately, the data required to eliminate transfers of output are available from the current dollar transactions tables in each of the six postwar interindustry studies used in this research. Faucett's output data for nonmanufacturing, adjusted for transfers and redefinitions, together with manufacturing data from the BEA, form a consistent set of time series for sectoral output for the period 1947–73, conforming to national income and product accounts industry definitions.

The need to include intermediate goods and services in a study of sectoral productivity is easily demonstrated. The supermarket manager

45. See Walderhaug (1973) for a full discussion of the redefinition and reclassification adjustments necessary to bridge national accounts and input-output definitions.

46. U.S. Department of Commerce, Bureau of Economic Analysis, "The Input-Output Structure of the U.S. Economy: 1967," *Survey of Current Business* 54 (February 1974); 56.

may choose to have his own employee display the frozen ice cream products in the frozen foods cabinet or he may contract with the raw materials supplier to have its deliveryman display the product. The former is a direct labor cost to the supermarket; the latter is an expense related to intermediate inputs. Presumably the store manager makes this choice such that the ratio of marginal products equals the corresponding ratio of factor prices. Should the marginal product of intermediate inputs increase, the manager may be capable of producing the same level of output with reduced labor and intermediate input requirements. Productivity change will be measured accurately only if all inputs are treated symmetrically.

The Bureau of Economic Analysis (1974*b*) makes available a complete set of data on intermediate input in current and constant prices for each of the manufacturing sectors (table 1.1). These data are constructed from disaggregated industry data according to industry definitions used in the national income and product accounts. We derive an estimate of intermediate input in current prices for nonmanufacturing industries by subtracting estimates of value added in current prices from the corresponding estimates of output in current prices described above. In converting these current price estimates into constant prices we take account of the composition of the intermediate inputs in each industry. Interindustry transactions in current prices published by the BEA are used to allocate intermediate input among the industries supplying each sector. Sectoral output deflators inclusive of indirect business taxes to the supplying sectors are used to convert the purchasing industry's intermediate input to constant prices.

### 1.4.2 Output and Intermediate Input

A measure of output in current and constant prices is essential to productivity measurement. The value of output is also indispensable in generating a measure of intermediate input. Data on output in current and constant prices for manufacturing sectors are available from the Interindustry Economics Division of the Bureau of Economic Analysis (1974*b*). Jack Faucett Associates (1975) has assisted the Bureau of Labor Statistics in developing data on output in current and constant prices for nonmanufacturing sectors classified according to the BLS Economic Growth Sectoring Plan, a 160-order classification of industries, and the BEA 80-order interindustry classification of industries. We have employed data from the BEA study of manufacturing industries directly. We have adjusted data from the Faucett study of nonmanufacturing industries to conform with industry definitions used in the national income and product accounts.

In table 1.28 we present a detailed cross-classification of industry definitions employed in the national income and product accounts, the

**Table 1.28 Industrial Classifications[a]**

| National Income (1) | Interindustry (2) | BLS (3) | SIC[b] (4) |
|---|---|---|---|
| 1 | *1,2 | 1–5 | 01[c] |
| 2 | *3,4 | 6,7 | 07,(–0713),08,09[d] |
| 3 | *5,6 | 8–10 | 10 |
| 4 | *7 | 11 | 11,12 |
| 5 | *8 | 12 | 13[e] |
| 6 | *9,10 | 13,14 | 14 |
| 7 | 11,12 | 15–20 | 15,16,17[f] |
| 8 | 14 | 23–32 | 20,0713[g] |
| 9 | 15 | 33 | 21 |
| 10 | 16,17,18.01–18.03 | 34–37 | 22 |
| 11 | 18.04,19 | 38–39 | 23[h] |
| 12 | 24,25 | 45–46 | 26 |
| 13 | 26 | 47–49 | 27 |
| 14 | 27–30 | 50–57 | 28[i] |
| 15 | 31 | 58 | 29 |
| 16 | 32 | 59–61 | 30 |
| 17 | 33,34 | 62 | 31 |
| 18 | 20,21 | 40–42 | 24 |
| 19 | 22,23 | 43–44 | 25 |
| 20 | 35,36 | 63–67 | 32 |
| 21 | 37,38 | 68–72 | 33[j] |
| 22 | 39–42 | 73–79 | 34 |
| 23 | 43–52 | 80–90 | 35 |
| 24 | 53–58 | 91–99 | 36 |
| 25 | 13,60,61 | 21,22,101–105 | 19,37(–371) |
| 26 | 59 | 100 | 371 |
| 27 | 62,63 | 106–110 | 38 |
| 28 | 64 | 111–113 | 39[k] |
| 29 | 65.01 | *114 | 40[l] |
| 30 | 65.02 | *115 | 41 |
| 31 | 65.03 | *116 | 42[m] |
| 32 | 65.04 | *117 | 44 |
| 33 | 65.05 | *118 | 45 |
| 34 | 65.06 | *119 | 46 |
| 35 | 65.07 | *120 | 47[n] |
| 36 | 66 | 121 | 48(–483) |
| 37 | 67 | 122 | 483 |
| 38 | 68.01 | *123 | 491,pt. 493 |
| 39 | 68.02,68.03 | *124 | 492,496,pt. 493[o] |
| 40 | 68.03 | *125 | 494,495,497[o] |
| 41 | 69.01 | *126 | 50 |
| 42 | 69.02 | *127 | 52–59,pt. 8099[p] |
| 43 | *70,71 | 128–132 | 60,61,63–67[q] |
| 44 | *72,73,75–77 | 133–146 | 70,72,73[r],75,76,78,79,80[s], 81,82,84,89[t] |
| 45 | 86 | 159 | 88 |

**Table 1.28** (continued)

| National Income (1) | Interindustry (2) | BLS (3) | SIC[b] (4) |
|---|---|---|---|
| 46 | 77.05 | 146 | 86[t] |
| 47 | pt. 84 | pt. 157 | 9190 |
| 48 | 78 | 147–149 | 9101–9189 |
| 49 | pt. 84 | pt. 157 | 9282,9382 |
| 50 | pt. 84 | pt. 157 | 9290,9390 |
| 51 | 79 | 150–151 | 9201–9289(–9282)<br>9301–9389(–9382) |

*Indicates whether Faucett's BLS or interindustry accounts data set was used for the nonmanufacturing national accounts sector identified in column (1). The absence of an asterisk in any line indicates either that we did not use the Faucett data for reasons described in the text or that Faucett reported no output estimates for that sector.

[a]Industry titles corresponding to each of the numerical references to national accounts sectors are listed separately in table 1.1. The digits used to identify the interindustry, BLS, and SIC industry boundaries are the conventional numerical codes respectively described in the *Survey of Current Business*, Faucett (1975), and Executive Office of the President (1967).

[b]The SIC codes correspond to national accounts definitions. Superscripted characters reference footnotes describing how interindustry accounts boundaries definitionally differ from the national accounts codes. Unless noted otherwise, all references to interindustry reclassifications apply also to the corresponding BLS sectors.

[c]Interindustry (I/O) sector 1.03 includes pt. 0729.

[d]I/O 4 includes 0713 and excludes 0722 and pt. 0729.

[e]I/O 8 excludes 138; BLS 12 includes 138.

[f]I/O 11.01 includes pt. 6561 and I/O 11.05 includes pt. 138. I/O 12.02 includes pt. 138; BLS 15–20 excludes 138.

[g]I/O 14 excludes 0713.

[h]I/O 18.04 includes 39996.

[i]I/O 27.01 excludes 28195.

[j]I/O 38.04 includes 28195.

[k]I/O 64.12 excludes 39996.

[l]I/O 65.01 includes 474.

[m]I/O 65.03 includes 473.

[n]I/O 65.07 excludes 473 and 474.

[o]I/O 68.03 includes 496 and pt. 493.

[p]I/O 69.02 includes 7396.

[q]I/O 71 excludes pt. 6561.

[r]I/O 73.01–.02 excludes 7396.

[s]I/O 77.03 includes 0722.

[t]I/O 77.05 includes 84, 86, 8921.

interindustry accounts, and the BLS Economic Growth Sectoring Plan.[47] Standard industrial classification (SIC) codes corresponding to each of

47. We include manufacturing industries in table 1.29 for completeness.

the three industrial classifications are given together with details on industrial classifications where exact correspondence with the SIC codes is lacking.[48] The first step in our procedure is to identify the BLS and interindustry classifications corresponding most closely to each nonmanufacturing industry from the national income and product accounts. Specifically, if a particular national accounts sector (for example, industry 4) maps exactly into one or more of Faucett's 80-order interindustry sectors (in this case, industry 7), we then chose the output series from that interindustry sector as a first approximation to the desired national accounts series. If, however, a national accounts sector (for example, industry 34) maps into only some disaggregated part of an interindustry sector's boundaries (in this example, industry 65.06) but into one or more BLS sectors (BLS industry 119), we then used Faucett's data for the BLS sectors as the initial estimate for the national accounts sector. In table 1.28, an asterisk identifies which of the two Faucett series was chosen as the initial estimate of output for each industry in the national accounts.

After initial estimates for each nonmanufacturing sector had been identified from the interindustry and BLS classifications, we adjusted data on the value of output in current prices to eliminate transfers among disaggregated BLS sectors within a single industry in the interindustry accounts. Eight of the sectors included in the interindustry accounts are the same as the corresponding sectors in the more detailed BLS accounts. For all but six sectors in the interindustry accounts the value of output is the sum of the values of outputs of the component sectors in the BLS accounts. However, for six sectors in the interindustry accounts,[49] the value of output is not equal to the sum of component sectors due to transfers within an industry. We adjusted data on the value of output for components of these six sectors to eliminate transfers, so that the value of output for each interindustry accounts sector is equal to the sum of the values of output of its components.

Finally, for a number of nonmanufacturing sectors (those lines in table 1.28 without an asterisk), we had to construct estimates of output from sources other than the Faucett report. First, the Faucett report publishes no results for the following nonmanufacturing sectors from the interindustry accounts:

48. Industry boundaries in the Economic Growth Sectoring Plan and the interindustry accounts are identical. Discrepancies listed in the notes to table 1.29 apply to the relationship between national income and product accounts definitions and the interindustry and equivalent BLS conventions.

49. The six interindustry sectors are numbered 6, 65, 68, 70, 73, and 77.

| Interindustry Accounts Sector | Name |
|---|---|
| 11 | New construction |
| 12 | Maintenance and repair construction |
| 66 | Communications, except radio and TV |
| 67 | Radio and TV broadcasting |
| 84 | Government industry |
| 86 | Household industry |

We obtained unpublished data on output in current and constant prices for contract construction from the Interindustry Economics Division of the BEA. These data are constructed according to conventions of the national income and product accounts, so that no further adjustments are required.

For the two communication sectors we constructed estimates of output in current and constant prices by moving the six current and constant price benchmarks from BEA studies of interindustry transactions[50] by the gross product originating series published annually in the July *Survey of Current Business* (1976*b*). By interpolating the ratios of gross product originating to output between benchmark years and using the intermediate-year figures we obtained output for the communication sectors.

Faucett found it unnecessary to construct estimates of output for government and household sectors, since value of production in these sectors is equivalent to value added. The Bureau of Economic Analysis prepares annual value-added estimates for the household and government sectors according to industry definitions from the national income and product accounts (1974*a*, 1977). Our annual value-added estimates for the household sector represent the sum of labor compensation, an estimate of the rental value of owner-occupied dwellings, and an estimate of the service flow of consumer durables. In the three government sectors (federal public administration, state and local educational services, and state and local public administration), the value-added totals equal labor compensation. Though the BEA is currently engaged in estimating capital stocks for each government sector, the data are not presently available. Since the value of output is wholly defined in terms of the value of inputs in the government and household

50. We employed BEA interindustry transaction data for 1947, 1958, 1961, 1963, 1966, and 1967. Data for 1958, 1963, and 1967 are published in the *Survey of Current Business* (1965, 1969, 1974*c*). Data fcr 1947, 1961, 1966 were obtained from unpublished studies by BEA (1968, 1970, 1972). The 1968, 1969, 1970, and 1971 transaction tables became available too late to be incorporated in this study.

sectors, no analysis of productivity change can be undertaken for national accounts sectors 45, 47, 49, and 50.

Second, although Faucett reports current and constant-dollar output series for nonprofit institutions and both federal and state and local enterprises, we chose not to adopt his estimates. For the two government enterprise sectors no estimates are available for capital services. An analysis of productivity change must await the completion of the Bureau of Economic Analysis study of capital stocks in all government sectors. Faucett's output estimates for nonprofit institutions are equivalent to value added. In place of the Faucett series, we applied a procedure like that used for the communications sectors to derive annual current and constant-dollar estimates of output in nonprofit institutions.

The output estimates for the manufacturing and contract construction sectors are used directly since they are constructed by conventions and industry definitions consistent with those used throughout the national income and product accounts. The value of output in these sectors includes all primary and secondary products originating in each producing sector. By contrast, our estimates of output for the communication sectors and nonprofit institutions and Faucett's output estimates for the remaining nonmanufacturing industries are derived according to the interindustry accounts convention of transferring into each sector the goods that are secondary to other industries but primary to the receiving sector. This results in the double counting of transferred output and would result in upward-biased estimates of intermediate inputs into each sector. Current dollar transactions tables available for each of the six interindustry accounts benchmark years make it possible to correct the Faucett series for transfers.

All output data presented by Faucett are set equal to output from the benchmark tables. In particular, Faucett's output in current prices equals the output reported in the transactions table minus imports that are allocated to that industry as substitute goods and import margins. To eliminate the secondary product transfers we employ the ratio of transfers to sector output reported in the 80-order or 367-order input-output tables.[51] Defining this ratio in terms consistent with Faucett's definition of output, a time series of output for each sector adjusted for transfers is formed by eliminating transfers from Faucett's unadjusted output series. We interpolated and extrapolated these ratios for the six benchmark years to obtain ratios for nonbenchmark years.[52]

51. Data for the more detailed tables are required for industries obtained from Faucett's BLS industry classification. The less detailed tables are required for industries from Faucett's interindustry classification.

52. The more detailed tables are available on a consistent basis only for 1963 and 1967.

In addition to secondary output transfers, activity redefinitions and SIC reclassifications account for important differences between the interindustry or BLS accounts and the national income and product accounts industry definitions, as indicated by Walderhaug:

> The GPO [NIPA gross product originating] estimates adhere strictly to the Standard Industrial Classification (SIC). In the I-O system, however, some industries are reclassified in order to achieve industry groups that are more homogeneous and that thus have a more stable input structure. [A sample of] these reclassifications consists of shifting veterinary services from the agricultural sector to the services sector, oil and gas field drilling services from mining to construction, and trading stamp companies from services to wholesale and retail trade. . . . [There are also] differences between the GPO and I-O value-added estimates that are due to the "redefinition" of certain activities [rather than whole SIC industries] from one industry to another. [Most] differences are due to the fact that in the I-O system all construction and installation work performed by employees in establishments not in the construction industry [i.e., force account construction] is redefined to be in the construction industry. [Other redefinitions include:] manufacturing and service activities that occur in the trade and transportation industries are shifted to the appropriate manufacturing and service industries; trade activities occurring in other industries are shifted to wholesale and retail trade; and manufacturer's sales offices are shifted from wholesale trade to manufacturing.[53]

Walderhaug kindly prepared and made available a full 80-order interindustry–national accounts reconciliation of 1963 industry value added that is similar to the more aggregated appendix table that appears in his contribution to the April 1973 issue of the *Survey of Current Business.* With this table we can calculate the fraction of net output (measured in current dollars) of each interindustry sector that had to be added to or subtracted from the Faucett interindustry or BLS sectors. If we had had data on redefined and reclassified output rather than value added, we would have required only the net addition to or subtraction from the output of each sector caused by redefinitions and reclassifications. However, given data on value added and the fact that the ratio of output to value added varies considerably across industries, we first identify the value added that was redefined or reclassified from each industrial sector and adjust it to reflect shifts in output. The adjustment for redefined and reclassified output is based on the ratio of value added redefined and reclassified for 1963 to total value added for that year. Since the Walderhaug table applies only to 1963, we were compelled to assume that the fractional addition or deduction reported by Walderhaug

53. Walderhaug (1973), pp. 42–43.

for each industry's value added remains constant for all years.[54] After adjusting the Faucett data series for transfers, redefinitions, and reclassifications, we obtained output series in current prices on the basis of industry definitions from the national income and product accounts.

The derivation of the output in constant prices from the BLS and interindustry series reported by Faucett was straightforward. In fact, we needed to make no adjustment to the Faucett series except for the redefinitions and reclassifications described above. Our elimination of secondary product transfers from data on output in current prices left each sector's output deflator unaffected. Transfers are treated as comparable to the primary output of the receiving rather than producing sectors. Consequently, in assigning deflators to secondary product flows, Faucett chose price indexes calculated from output in current and constant prices for goods actually produced in the receiving sector. These deflators required no alterations for our estimates of output in current prices for industrial sectors from the national income and product accounts. The same conclusion applies to the shifts of redefined and reclassified industry output away from a given sector. The products within each sector have a common deflator. Reclassifying some of the sector's output elsewhere leaves the supplying sector's deflator unaffected. Transfers of redefined or reclassified output into a given sector, however, would affect the output deflator for the receiving sector. We adjusted Faucett's price index for output to reflect the price movements in the industries in which the redefined or reclassified goods originate.

We have described the construction of output in accord with industry definitions from the national income and product accounts. One final adjustment to output in current prices is required; output must be valued in producers' prices—that is, exclusive of trade and transportation margins and all indirect business taxes. The current dollar series for manufacturing and construction taken directly from the national accounts and estimated for nonmanufacturing sectors from Faucett's data are net of trade and transportation margins but gross of sales and excise taxes. We thus subtracted from each industry's current dollar value of output the dollar value of sales and excise taxes reported in the national income and product accounts by the Bureau of Economic Analysis. This implies a symmetrical adjustment to each sector's output deflator since, while taxes do not affect the measure of constant dollar output, the elimination of indirect business taxes alters the series of producers' prices for output. The adjusted deflator is calculated by dividing the original deflator gross of sales and excise taxes by $(1+t)$, where $t$ is the indirect tax rate.

54. This assumption was also made by Faucett (1975), so that our adjustments are consistent with those made by Faucett.

Data on intermediate input in current and constant prices are available for the manufacturing industries listed in table 1.1 above from the Bureau of Economic Analysis. These data are classified on the basis of the industry definitions employed in the national income and product accounts and can be employed directly in our study. For the nonmanufacturing industries we have constructed estimates of output in current and constant prices as described in the preceding section. Data on value added in these industries are available in current prices from the Bureau of Economic Analysis. We constructed estimates of intermediate input in current prices by subtracting value added from output, both in current prices. The problem that remains is to construct estimates of intermediate input in constant prices.

Our first step in constructing estimates of intermediate input in constant prices was to determine the ratio of intermediate input in current prices to output in current prices for each of the sectors from the interindustry accounts and BLS accounts employed in our construction of estimates of output in current prices. These ratios were obtained from tables of interindustry transactions constructed by the Bureau of Economic Analysis; for years that interindustry transaction tables were unavailable, we obtained these ratios by interpolation and extrapolation. Our second step was to obtain estimates of the current dollar value of intermediate input for each industry in the interindustry and BLS accounts by multiplying that industry's ratio of the value of intermediate input to the value of output by the value of its redefinition, reclassification, and transfer adjusted output. We adjusted these estimates so that the current dollar value of intermediate input for each industry in the national income and product accounts is equal to the sum of its interindustry or BLS accounts components. The interindustry and BLS accounts sectors corresponding to each industry from the national income and product accounts are indicated in table 1.28. We assumed that the ratio of the value of intermediate input to the value of output was the same for industries classified according to interindustry accounting definitions as for industries classified according to national income and product accounting conventions.

Third, after allocating intermediate input in current prices among the appropriate interindustry and BLS accounts sectors, we identified the source industries producing those goods as final products and used output deflators in purchasers' prices for each industry to convert deliveries of intermediate input into constant prices. The exact procedure adopted to accomplish this result can be described as follows. Using the input-output coefficients in current prices published in the six benchmark input-output studies, we allocated intermediate input by sector of origin for each industry. These coefficients are interpolated and extrapolated to obtain shares of intermediate input by sector of origin for each industry for all years. Finally, the output deflators for each sector of origin are weighted by the corresponding shares to obtain a deflator for intermediate input for each industry. Finally, having deflated the current dollar value of intermediate input into each interindustry and BLS accounts sector, we summed the resulting constant dollar quantities of intermediate input for all sectors included in an industry from the national income and products accounts to obtain intermediate input in that national accounts sector.

It is important to note that the output deflator used in measuring the current dollar value of a sector's output is not equivalent to the deflator used in evaluating the current dollar value of that sector's output as intermediate input into a purchasing sector's production process. The former is measured in producers' prices; the latter is measured in consumers' prices. The former is net of all sales and excise taxes and trade and transportation margins; the latter is gross of sales and excise taxes attributed to the output of the sector supplying the intermediate input. The trade and transportation margins paid by the consuming sector are captured in the intermediate input flows from the trade and transport sectors.

A final issue in measuring output and intermediate input involves the use of energy consumption to adjust potential capital services for the actual level of services utilized. This approach, originally introduced by Griliches and Jorgenson (1966), was subsequently withdrawn by Christensen and Jorgenson (1973). Kendrick has argued that capital stock should not be adjusted for utilization:

> In contrast to the human population, the entire living population of capital goods is available for productive use at all times, and involves a per annum cost, regardless of degree of use. The purpose of capital assets is for use in production of current output and income. The degree of capital utilization reflects the degree of efficiency of enterprises and the social economy generally. Hence, in converting capital stocks into inputs, we do not adjust capital for changes in rates of capacity utilization, and thus these are reflected in changes in the productivity ratios.[55]

Denison also argues against adjustment for utilization:

> In the short run, the intensity of capital utilization fluctuates with variations in the pressure of demand, but in this respect capital input is not different from land input or labor input. . . . The hours that capital is used may also change in the longer run but such changes,

55. Kendrick (1973), p. 26.

> if they occur, are merely manifestations of changes in other output determinants that are separately measured so need not be given separate consideration.[56]

The use of energy per unit of capital input employed as a relative utilization adjustment by Griliches and Jorgenson (1966) and Jorgenson and Griliches (1967, 1972) involves the substitution of energy, a component of intermediate input, for capital. This substitution is fully accounted for in our measures of intermediate input, since these measures are based on a model of production and technical change that incorporates substitution among intermediate, capital, and labor inputs as well as the rate of technical change. No further adjustment of capital input or intermediate input is required.

### 1.4.3 Indexes of Productivity

We have described the development of data on prices and quantities of output and intermediate input for each industrial sector. We have generated prices and quantities of output for all fifty-one industrial sectors of the private domestic sector of the U.S. economy listed in table 1.1. For six of these sectors—private households and the five government sectors—output is equal to value added and intermediate input is zero. We have generated prices and quantities of intermediate input for the remaining forty-five industrial sectors. Rates of growth of output for all fifty-one sectors and rates of growth of intermediate input for forty-five sectors are presented in table 1.29.

To construct an index of productivity for each industrial sector we assume that sectoral output $\{Z_i\}$ can be expressed as a translog function of sectoral intermediate input $\{X_i\}$, capital input $\{K_i\}$, and labor input $\{L_i\}$. The corresponding index of productivity is the translog index of sectoral technical change $\{\bar{v}^i_T\}$:

$$\begin{aligned} \bar{v}^i_T = {} & [\ln Z_i(T) - \ln Z_i(T-1)] \\ & - \bar{v}^i_X [\ln X_i(T) - \ln X_i(T-1)] \\ & - \bar{v}^i_K [\ln K_i(T) - \ln K_i(T-1)] \\ & - \bar{v}^i_L [\ln L_i(T) - \ln L_i(T-1)], \end{aligned} \qquad (i = 1, 2, \ldots, n),$$

where weights are given by average shares of sectoral intermediate input, capital input, and labor input in the value of sectoral output:

56. Denison (1974), p. 56.

$$\bar{v}^i_T = 1/2\ [v^i_T(T) + v^i_T(T-1)],$$

$$\bar{v}^i_X = 1/2\ [v^i_X(T) + v^i_X(T-1)],$$

$$\bar{v}^i_K = 1/2\ [v^i_K(T) + v^i_K(T-1)],$$

$$\bar{v}^i_L = 1/2\ [v^i_L(T) + v^i_L(T-1)], \quad (i = 1, 2, \ldots, n),$$

and

$$v^i_X = \frac{p^i_X X_i}{q_i Z_i},$$

$$v^i_K = \frac{p^i_K K_i}{q_i Z_i},$$

$$v^i_L = \frac{p^i_L L_i}{q_i Z_i}, \qquad (i = 1, 2, \ldots, n).$$

The value shares are computed from data on output and its price $\{q_i\}$, intermediate input and its price $\{p^i_X\}$, capital input and its price $\{p^i_K\}$, and labor input and its price $\{p^i_L\}$. The value of output is equal to the sum of the values of intermediate, capital, and labor input.

We have generated translog indexes of productivity for each industrial sector listed in table 1.1. For the five government sectors output is equal to labor input, so that productivity change is zero. For private households output is equal to an index of capital and labor input; again, productivity change is zero. For the remaining forty-five sectors we present indexes of productivity in table 1.30. To facilitate comparisons with indexes of productivity for value added developed by Kendrick, we have generated translog indexes of productivity for value added $\{\bar{v}_{VT}\}$ for each industrial sector for the period 1948–66, the period covered by Kendrick's study. These indexes are generated from the translog indexes for output as follows:

$$\bar{v}^i_{VT} = \bar{v}^i_V\, \bar{v}^i_T, \qquad (i = 1, 2, \ldots, n),$$

where the weights $\{\bar{v}^i_V\}$ are given by the average shares of value added in the value of sectoral output. Value added is equal to the sum of the values of capital and labor input. For comparison, indexes employed by Kendrick are presented for each industry included in his study. These indexes have been taken directly from his *Postwar Productivity Trends in the United States: 1948–1969* (1973).

**Table 1.29** **Output and Intermediate Input: Rates of Growth**

| | Output (average annual rates of growth) | | | | | | Intermediate Input (average annual rates of growth) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Industry | 1947–1973 | 1947–1953 | 1953–1957 | 1957–1960 | 1960–1966 | 1966–1973 | 1947–1973 | 1947–1953 | 1953–1957 | 1957–1960 | 1960–1966 | 1966–1973 |
| Agricultural production | .0179 | .0114 | .0223 | .0184 | .0162 | .0222 | .0144 | —.0011 | .0238 | .0066 | .0210 | .0201 |
| Agricultural services | .0306 | .0517 | .0110 | .0418 | .0107 | .0359 | .0484 | .0692 | .0349 | .0780 | —.0168 | .0815 |
| Metal mining | .0178 | .0317 | .0194 | —.0053 | .0075 | .0237 | .0474 | .1012 | .0054 | .0169 | —.0181 | .0946 |
| Coal mining | —.0086 | —.0592 | .0122 | —.0604 | .0306 | .0115 | .0017 | —.0548 | —.0043 | —.0635 | .0199 | .0658 |
| Crude petroleum and natural gas | .0304 | .0537 | .0350 | .0094 | .0235 | .0225 | .0323 | .0283 | .0223 | .0058 | .0555 | .0330 |
| Nonmetallic mining and quarrying | .0479 | .0553 | .0720 | .0395 | .0466 | .0325 | .0447 | .0403 | .0993 | .0473 | .0490 | .0126 |
| Contract construction | .0379 | .0674 | .0411 | .0403 | .0348 | .0125 | .0429 | .0832 | .0484 | .0244 | .0363 | .0187 |
| Food and kindred products | .0292 | .0192 | .0294 | .0514 | .0232 | .0331 | .0282 | .0160 | .0277 | .0663 | .0241 | .0262 |
| Tobacco manufacturers | .0125 | .0066 | —.0017 | .0639 | .0030 | .0118 | .0040 | .0096 | —.0326 | .0618 | —.0091 | .0065 |
| Textile mill products | .0442 | .0329 | .0061 | .0336 | .0635 | .0637 | .0446 | .0408 | .0000 | .0398 | .0679 | .0555 |
| Apparel and other fabr. textile prod. | .0345 | .0308 | .0293 | .0227 | .0406 | .0406 | .0344 | .0218 | .0483 | .0188 | .0469 | .0331 |
| Paper and allied products | .0434 | .0436 | .0285 | .0366 | .0551 | .0447 | .0462 | .0510 | .0371 | .0358 | .0517 | .0469 |
| Printing and publishing | .0332 | .0201 | .0432 | .0447 | .0436 | .0250 | .0363 | .0288 | .0414 | .0681 | .0396 | .0233 |

**Table 1.29 (continued)**

| Industry | Output (average annual rates of growth) 1947–1973 | 1947–1953 | 1953–1957 | 1957–1960 | 1960–1966 | 1966–1973 | Intermediate Input (average annual rates of growth) 1947–1973 | 1947–1953 | 1953–1957 | 1957–1960 | 1960–1966 | 1966–1973 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chemicals and allied products | .0681 | .0722 | .0610 | .0632 | .0769 | .0632 | .0584 | .0627 | .0492 | .0612 | .0723 | .0467 |
| Petroleum and coal products | .0408 | .0566 | .0311 | .0310 | .0336 | .0431 | .0379 | .0602 | .0334 | .0307 | .0238 | .0366 |
| Rubber and misc. plastic products | .0578 | .0397 | .0113 | .0768 | .0789 | .0736 | .0599 | .0433 | .0327 | .0775 | .0818 | .0632 |
| Leather and leather products | .0028 | −.0052 | .0038 | −.0038 | .0107 | .0050 | .0030 | .0109 | .0194 | −.0096 | .0000 | −.0052 |
| Lumber and wood prod. excluding furniture | .0240 | .0136 | .0046 | .0372 | .0357 | .0283 | .0277 | .0352 | .0133 | .0548 | .0259 | .0194 |
| Furniture and fixtures | .0390 | .0370 | .0245 | .0256 | .0535 | .0425 | .0411 | .0411 | .0293 | .0422 | .0570 | .0337 |
| Stone, clay, and glass products | .0407 | .0553 | .0340 | .0441 | .0455 | .0265 | .0480 | .0746 | .0427 | .0640 | .0440 | .0247 |
| Primary metal industries | .0227 | .0503 | −.0310 | −.0188 | .0615 | .0143 | .0287 | .0533 | −.0245 | −.0055 | .0591 | .0265 |
| Fabricated metal industries | .0357 | .0457 | .0085 | .0196 | .0548 | .0332 | .0349 | .0463 | .0052 | .0242 | .0547 | .0297 |
| Machinery excluding electrical | .0412 | .0413 | −.0062 | .0101 | .0916 | .0384 | .0415 | .0446 | −.0091 | .0201 | .0908 | .0346 |
| Elec. machinery, eqpt., and supplies | .0612 | .0834 | −.0048 | .0645 | .1065 | .0397 | .0505 | .0769 | −.0241 | .0635 | .0904 | .0306 |

**Table 1.29** (continued)

| Industry | Output (average annual rates of growth) 1947–1973 | 1947–1953 | 1953–1957 | 1957–1960 | 1960–1966 | 1966–1973 | Intermediate Input (average annual rates of growth) 1947–1973 | 1947–1953 | 1953–1957 | 1957–1960 | 1960–1966 | 1966–1973 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trans. eqpt. and ex. motor vehicles | .0550 | .2191 | —.0249 | —.0411 | .0625 | —.0054 | .0543 | .2368 | —.0368 | —.0475 | .0515 | —.0042 |
| Motor vehicles and equipment | .0483 | .0753 | —.0021 | .0224 | .0676 | .0487 | .0460 | .0775 | —.0091 | .0096 | .0688 | .0464 |
| Prof. photographic eqpt. and watches | .0559 | .0685 | .0138 | .0831 | .0590 | .0549 | .0479 | .0628 | .0164 | .0845 | .0600 | .0272 |
| Misc. manufacturing industries | .0386 | .0323 | .0052 | .0676 | .0509 | .0402 | .0375 | .0247 | .0020 | .0904 | .0533 | .0326 |
| Railroads and rail express service | —.0052 | —.0174 | —.0021 | —.0197 | —.0062 | .0106 | —.0259 | —.0150 | —.0305 | —.0078 | —.0882 | .0130 |
| Street rail., bus lines, and taxicabs | —.0459 | —.0583 | —.0360 | —.0357 | —.0784 | —.0175 | —.0647 | —.0272 | —.0333 | —.0346 | —.1758 | —.0323 |
| Trucking services and warehousing | .0457 | .1241 | .0393 | .0308 | —.0107 | .0367 | .0324 | .1215 | .0219 | .0283 | —.0647 | .0471 |
| Water transportation | .0083 | —.0464 | .0511 | —.0582 | .0080 | .0596 | —.0030 | —.0318 | .0209 | —.0441 | —.0179 | .0386 |
| Air transportation | .1068 | .1459 | .1204 | .0958 | .0868 | .0874 | .0687 | .1115 | .0827 | .1249 | .0187 | .0430 |
| Pipelines ex. natural gas | .0474 | .0795 | .0654 | .0180 | .0088 | .0554 | —.0152 | .0518 | .0599 | .0330 | —.1217 | —.0449 |
| Transportation services | —.0079 | —.0072 | .0319 | —.0676 | —.0739 | .0510 | —.0017 | .0046 | .0994 | —.0735 | —.1366 | .0814 |
| Telephone, telegraph, misc. comm. services | .0712 | .0763 | .0564 | .0536 | .0804 | .0749 | .0582 | .0656 | .0294 | .0381 | .0689 | .0676 |

**Table 1.29** (continued)

Table 1.29 (continued)

| Industry | Output (average annual rates of growth) 1947–1973 | 1947–1953 | 1953–1957 | 1957–1960 | 1960–1966 | 1966–1973 | Intermediate Input (average annual rates of growth) 1947–1973 | 1947–1953 | 1953–1957 | 1957–1960 | 1960–1966 | 1966–1973 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Radio broadcasting and television | .0668 | .1182 | .0658 | .0357 | .0515 | .0498 | .0672 | .1123 | .0316 | .0566 | .0864 | .0371 |
| Electric utilities | .0665 | .0803 | .0673 | .0620 | .0644 | .0580 | .0541 | .0247 | .0323 | .0273 | .0866 | .0753 |
| Gas utilities | .0702 | .1224 | .0745 | .0666 | .0504 | .0415 | .0777 | .1396 | .0867 | .0943 | .0420 | .0430 |
| Water supply and sanitary services | .0392 | .0649 | .0062 | .0545 | .0468 | .0231 | .0448 | −.0058 | −.0089 | .0972 | .1055 | .0444 |
| Wholesale trade | .0465 | .0327 | .0442 | .0561 | .0610 | .0430 | .0445 | .0258 | .0316 | .0890 | .0693 | .0278 |
| Retail trade | .0306 | .0267 | .0294 | .0134 | .0371 | .0364 | .0164 | −.0045 | .0157 | −.0074 | .0155 | .0456 |
| Finance, insurance, and real estate | .0493 | .0402 | .0613 | .0374 | .0489 | .0559 | .0663 | .0251 | .1276 | .0193 | .0432 | .1067 |
| Services, excl. priv. households and institutions | .0384 | .0224 | .0368 | .0322 | .0506 | .0450 | .0538 | .0367 | .0443 | .0252 | .0633 | .0779 |
| Private households | .0512 | .0801 | .0552 | .0342 | .0359 | .0444 | | | | | | |
| Institutions | .0355 | .0352 | .0308 | .0550 | .0462 | .0208 | .0224 | .0211 | .0149 | .0217 | .0428 | .0106 |
| Federal public administration | .0175 | .0449 | −.0099 | .0029 | .0322 | .0032 | | | | | | |
| Federal government enterprises | .0199 | .0358 | .0063 | .0281 | .0237 | .0073 | | | | | | |
| State and local: | | | | | | | | | | | | |
| Educ. services | .0526 | .0535 | .0568 | .0591 | .0571 | .0429 | | | | | | |
| Public administration | .0400 | .0484 | .0385 | .0238 | .0421 | .0387 | | | | | | |
| Gov't enterprises | .0409 | .0802 | −.0011 | .0634 | .0233 | .0366 | | | | | | |

**Table 1.30 Productivity: Rates of Growth**

| Industry | Total Factor Productivity 1948–1966 (average annual rates of growth) | | Translog Index of Productivity (average annual rates of growth) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Kendrick | Translog | 1947–1973 | 1947–1953 | 1953–1957 | 1957–1960 | 1960–1966 | 1966–1973 |
| Agricultural production | | .0379 | .0168 | .0194 | .0221 | .0202 | .0147 | .0120 |
| Agricultural services | | −.0038 | −.0085 | .0033 | −.0062 | .0100 | −.0113 | −.0254 |
| Metal mining | .0239 | −.0335 | −.0155 | −.0363 | .0065 | −.0353 | .0120 | −.0253 |
| Coal mining | .0508 | .0356 | −.0002 | −.0222 | .0501 | .0128 | .0223 | −.0349 |
| Crude petroleum and natural gas | .0319 | .0171 | .0098 | .0360 | .0096 | .0098 | −.0071 | .0020 |
| Nonmetallic mining and quarrying | .0260 | −.0094 | −.0000 | −.0243 | .0000 | .0011 | .0007 | .0197 |
| Contract construction | .0146 | .0137 | .0007 | .0009 | .0089 | .0223 | −.0016 | −.0116 |
| Food and kindred products | | −.0097 | .0001 | .0005 | .0090 | −.0466 | .0030 | .0123 |
| Tobacco manufacturers | .0108 | .0079 | .0028 | −.0048 | .0238 | −.0335 | .0080 | .0085 |
| Textile mill products | .0395 | .0374 | .0154 | .0062 | .0173 | .0190 | .0131 | .0225 |
| Apparel and other fabr. textile prod. | .0188 | .0077 | .0067 | .0110 | .0027 | −.0144 | .0020 | .0183 |
| Paper and allied products | .0249 | .0046 | .0001 | −.0064 | −.0077 | −.0224 | .0124 | .0094 |
| Printing and publishing | .0262 | .0143 | .0057 | −.0000 | .0211 | −.0306 | .0187 | .0061 |
| Chemicals and allied products | .0475 | .0468 | .0233 | .0206 | .0208 | .0269 | .0218 | .0267 |
| Petroleum and coal products | .0296 | −.0208 | .0069 | .0095 | .0002 | −.0134 | .0162 | .0094 |
| Rubber and misc. plastic products | .0386 | .0269 | .0099 | .0025 | −.0174 | .0433 | .0084 | .0187 |
| Leather and leather products | .0165 | −.0379 | −.0068 | −.0132 | −.0038 | −.0871 | .0088 | .0179 |
| Lumber and wood prod. excluding furniture | .0341 | −.0063 | −.0061 | −.0285 | .0107 | −.0691 | .0177 | .0102 |
| Furniture and fixtures | .0290 | .0049 | .0121 | .0401 | .0086 | −.0352 | .0068 | .0148 |
| Stone, clay, and glass products | .0240 | .0132 | .0023 | .0004 | .0010 | −.0269 | .0143 | .0070 |
| Primary metal industries | .0157 | −.0079 | −.0049 | .0094 | −.0174 | −.0594 | .0160 | −.0046 |
| Fabricated metal industries | .0184 | .0045 | .0019 | .0039 | .0012 | −.0329 | .0096 | .0090 |
| Machinery excluding electrical | .0256 | .0102 | .0055 | .0080 | −.0064 | −.0272 | .0218 | .0105 |
| Elec. machinery, eqpt., and supplies | .0364 | .0367 | .0148 | .0081 | −.0013 | .0006 | .0380 | .0160 |

**Table 1.30** (continued)

| Industry | Total Factor Productivity 1948–1966 (average annual rates of growth) | | Translog Index of Productivity (average annual rates of growth) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Kendrick | Translog | 1947–1973 | 1947–1953 | 1953–1957 | 1957–1960 | 1960–1966 | 1966–1973 |
| Trans. eqpt. and ord. ex. motor vehicles | | .0207 | .0074 | .0297 | −.0065 | −.0324 | .0161 | .0059 |
| Motor vehicles and equipment | | .0171 | .0054 | .0075 | .0057 | −.0183 | .0092 | .0104 |
| Prof. photographic eqpt. and watches | .0310 | .0154 | .0066 | −.0153 | −.0101 | .0219 | .0115 | .0243 |
| Misc. manufacturing industries | .0288 | .0221 | .0085 | .0014 | .0097 | −.0020 | .0107 | .0166 |
| Railroads and rail express service | .0340 | .0513 | .0220 | .0060 | .0294 | .0121 | .0436 | .0171 |
| Street rail., bus lines, and taxicabs | | −.0266 | −.0099 | −.0335 | −.0022 | −.0064 | .0057 | −.0087 |
| Trucking services and warehousing | | .0355 | .0067 | .0217 | .0153 | −.0009 | .0013 | −.0033 |
| Water transportation | .0506 | .0281 | .0122 | −.0341 | .0374 | −.0176 | .0191 | .0443 |
| Air transportation | .0053 | .0970 | .0382 | .0588 | .0355 | −.0114 | .0485 | .0345 |
| Pipelines ex. natural gas | .0769 | .0814 | .0542 | .0568 | .0437 | .0196 | .0635 | .0647 |
| Transportation services | | −.0733 | −.0165 | −.0058 | −.0363 | −.0255 | −.0279 | −.0007 |
| Telephone, telegraph, and misc. comm. services | .0400 | .0339 | .0233 | .0325 | .0261 | .0308 | .0217 | .0121 |
| Radio broadcasting and television | | .0018 | .0010 | .0230 | .0000 | −.0195 | −.0205 | .0097 |
| Electric utilities | | .0561 | .0266 | .0565 | .0339 | .0396 | .0207 | −.0035 |
| Gas utilities | | .0319 | .0114 | .0171 | .0259 | −.0146 | .0182 | .0037 |
| Water supply and sanitary services | | .0069 | −.0001 | .0482 | −.0128 | −.0010 | −.0092 | −.0259 |
| Wholesale trade | .0245 | .0185 | .0121 | −.0023 | .0214 | .0128 | .0196 | .0122 |
| Retail trade | .0238 | .0265 | .0132 | .0138 | .0190 | .0053 | .0215 | .0055 |
| Finance, insurance, and real estate | | .0080 | .0021 | .0021 | −.0065 | .0109 | .0167 | −.0093 |
| Services, excl. priv. households and institutions | | .0015 | .0004 | .0006 | .0049 | −.0013 | .0038 | −.0045 |
| Institutions | | −.0006 | −.0003 | −.0006 | −.0017 | −.0012 | .0005 | .0007 |

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## Comment Ernst R. Berndt

The Gollop-Jorgenson (hereafter GJ) paper represents the culmination of a mammoth project involving an enormous amount of data gathering, consultation with government statistical officials, and data manipulation. Even without adjusting for the obvious quality of the labor input, one cannot help but be overwhelmed with the massive real factor input embodied in this paper. Annual productivity measures are obtained for each of 51 industries over the 1947–73 period;[1] labor data are broken down into classifications of sex (two groups), age (eight), occupation (ten), education (five), and type of employment (two). Capital data

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The original versions of the paper and comments were prepared for presentation at the NBER Conference on New Developments in Productivity Measurement, Williamsburg, Virginia, 1975 November 13–14. The comments below are on the revised version of the Gollop-Jorgenson paper, dated September 1977. I have benefited from discussions with Dale W. Jorgenson, who clarified a number of issues regarding data procedure.

1. In the original version of the paper, data were prepared for 67 industries. The finance, insurance, and real estate sectors, among others, have been aggregated in the revised version.

are disaggregated into three types of organization (corporate business, noncorporate business, households and institutions), and six asset classes (producers' durable equipment, consumers' durable equipment, residential structures, nonresidential structures, inventories, and land). Finally, intermediate goods are introduced into the growth accounting framework. Thus this paper represents an enormous effort in applied economic research.

In addition to the presentation of indices of total factor productivity for each of 51 industries, the GJ study offers three substantial discussions: (i) theoretical underpinnings for the indexing of total factor productivity, (ii) the derivation, calculation, and interpretation of labor and capital quality indices, and (iii) the introduction of intermediate goods into growth accounting.

In these comments I will focus most of my attention on theoretical underpinnings, crucial assumptions, and method of approach.[2] I begin with a discussion of theoretical underpinnings.

If we wish to obtain indices of total factor productivity, it is imperative that we first develop a clear notion of what it is that we are trying to measure. Historically, the theory and practice of indexing was closely associated with the theory of production. In recent years substantial developments in the theory of production, cost, and duality have taken place; a number of these developments are explicitly incorporated into the GJ paper.

Suppose there exists a transformation function relating inputs (denoted $X_1, X_2, \ldots, X_n$) and outputs (denoted $Y_1, Y_2, \ldots, Y_m$) at different points in time (denoted by $t$). More formally, let us specify a general transformation function of the form

$$H(Y_{1t},Y_{2t}, \ldots, Y_{mt}; X_{1t},X_{2t}, \ldots, X_{nt}; t) = 0, \tag{1}$$

where $H$ satisfies the appropriate differentiability and curvature properties. Let us denote a scalar index of the $m$ outputs at time $t$ as $Y_t$, a scalar index of the $m$ inputs as $X_t$, and the time derivaties as $\dot{Y}/Y$ and $\dot{X}/X$. The index of total factor productivity (hereafter TFP) is typically computed as

$$\text{TFP} = \frac{\dot{Y}}{Y} - \frac{\dot{X}}{X}. \tag{2}$$

This suggests that one might want to ask what conditions must be placed on (1) in order to measure TFP in the above manner. A set of sufficient conditions is that a consistent index of aggregate output and a

2. These revised comments are considerably shorter than in the original version, since a number of suggestions have been incorporated by GJ in their revised paper.

consistent index of aggregate input exists; thus it is assumed that (1) can be written in the homothetic weakly separable form

$$(3) \qquad \begin{aligned} &H\,(Y_{1t},Y_{2t},\ldots Y_{mt};\,X_{1t},X_{2t},\ldots,X_{nt};\,t)\\ &= H^{*}\,[G^{*}\,(Y_{1t},Y_{2t},\ldots,Y_{mt}),F^{*}\,(X_{1t},X_{2t},\ldots X_{nt})]\\ &= H^{**}[G^{**}(Y_t),\,F^{**}(X_t,t)], \end{aligned}$$

where $Y_t$ and $X_t$ are "composite goods" or "consistent aggregates." If in addition it is assumed that the homothetic separability is of the additive type, we can specify the familiar production function

$$(4) \qquad G\,(Y_t) - F\,(X_t,t) = 0, \text{ or } G\,(Y_t) = F\,(X_t,t).$$

Gollop and Jorgenson also assume that $G$ and $F$ are characterized by constant returns to scale. While this assumption is not necessary, it traditionally has been convenient for purposes of data construction and accounting. Under these assumptions, the notion of total factor productivity is simply the partial derivative

$$(5) \qquad \epsilon_{Ft} = \frac{\partial \ln F\,(X_t,t)}{\partial t}, \text{ input quantities fixed,}$$

which is approximated empirically by (2).

An alternative notion of TFP can be derived using the theory of duality. If $H$, $G$, and $F$ have the appropriate curvature properties and input markets are competitive, then corresponding with the production function (4) there exists a dual cost function of the form

$$(6) \qquad C_t = C^{*}\,(Y_t,\,P_{1t},P_{2t},\ldots,P_{nt},\,t),$$

where $C$ is the minimum total cost of producing output $Y$, and $P_1,P_2,\ldots,P_n$ is the vector of input prices. The elasticity of costs with respect to output is defined as

$$(7) \qquad \epsilon_{CY} = \frac{\partial \ln C}{\partial \ln Y}, \text{ input prices fixed}$$

and the associated dual rate of returns to scale is of course

$$(8) \qquad \epsilon^{-1}{}_{CY} \equiv \frac{1}{\epsilon_{CY}} = 1/(\partial \ln C/\partial \ln Y).$$

Finally, one can define the dual rate of total cost diminution as

$$(9) \qquad \epsilon_{Ct} = \frac{-\partial \ln C}{\partial t}, \text{ input prices and output quantity fixed.}$$

Naturally the question arises as to the relationship between total factor productivity (5) viewed from the primal and total cost diminution (9) viewed from the dual. Makoto Ohta (1974) has shown that, in general,

$$(10) \qquad \epsilon_{Ft} = \epsilon^{-1}{}_{CY}\, \epsilon_{Ct},$$

i.e., total factor productivity viewed from the primal side is equal to dual returns to scale times the rate of total cost diminution. If returns to scale are greater than unity, then of course $\epsilon_{Ft} > \epsilon_{Ct}$. In the GJ framework where constant returns to scale are imposed, $\epsilon_{Ft} = \epsilon_{Ct}$, i.e.,

$$(11) \qquad \frac{\partial \ln F(X_t,t)}{\partial t} = \frac{-\partial \ln C(P_t,Y_t,t)}{\partial t},$$

where $P_t$ is a vector of the $n$ input prices. Hence in the present context the primal and dual notions of productivity are equal.

It should be noted that this notion of total factor productivity as presented by GJ does not require neutrality of technical change. TFP is simply a time derivative—which can be the outcome of nonneutral technical change. Indeed, TFP can be viewed as a weighted sum of input-specific technological change biases. Suppose, for example, that technical change is of the constant exponential factor augmenting form

$$(12) \qquad X^*_{it} = X_{it}\, exp\, (\lambda_i T), \quad i = 1, \ldots, n,$$

or, equivalently, of the input price diminishing form

$$(13) \qquad P^*_{it} = P_{it} \exp\, (-\lambda_i T),$$

where $X^*_{it}$ and $X_{it}$ are input quantities measured in efficiency and "natural" units, respectively, $P^*_{it}$ and $P_{it}$ are input prices measured in efficiency and "natural" units, $T = t - t_o$, where $t_o$ is an initial point in time, and $\lambda$ is the constant exponential rate of factor quantity augmentation (price diminution). It can be shown that total factor productivity is the weighted sum of input augmentation rates

$$(14) \qquad \text{TFP} = \frac{\partial \ln G}{\partial t} = - \frac{\partial \ln C}{\partial t} = \sum_{i=l}^{m} M_i \lambda_i,$$

where $M_i$ is the cost or value share of the $i$th input in total cost or total value. Thus TFP does not require neutrality of technical change.[3] Incidentally, in the above example, the rate of total factor productivity is endogenous; exogenous rates of augmentation for each input are weighted by endogenous cost-minimizing factor shares.

The above represents theoretical underpinnings of TFP measurement. It might be noted that TFP in the Gollop-Jorgenson framework is clearly restricted to the production sector; in particular, TFP has no

3. A clear statement of nonneutral technical change and TFP in the context of a CES production function is offered by Paul A. David and Th. van de Klundert, "Biased Efficiency Growth and Capital-Labor Substitution in the U.S., 1899–1969," *American Economic Review* 55 (1965): 357–94. An analogous presentation for translog cost functions is found in Berndt and Jorgenson (1975).

clear relationship to "welfare" or "social well-being," even when prices accurately reflect social costs.

In the revised version of their paper, Gollop and Jorgenson specify the vital link between the production or cost function and the precise index-number formulas. The issue here is how one empirically approximates the derivatives $\partial \ln G/\partial t$ or $\partial \ln C/\partial t$ in (11).

Let us denote the output of a specific production-functional form $F$ at times $t$ and $t-1$ as $Y_t$ and $Y_{t-1}$, and particular index-number measures of output as $I_t$ and $I_{t-1}$. The particular index number is said to be *exact* for the functional form $F$ if[4]

$$\frac{Y_t}{Y_{t-1}} = \frac{I_t}{I_{t-1}}. \tag{15}$$

Gollop and Jorgenson employ a discrete version of the Divisia index developed by Törnqvist. Thus it is of interest to ask what the functional form is for which the Törnqvist index is exact. Diewert has shown that if the production function is homogeneous translog, then the Törnqvist quantity index will be exact; similarly, if the cost function is homogeneous translog, then the Törnqvist price index will be exact. This then provides a theoretical foundation for using the Törnqvist index in productivity analyses and explains why GJ call their index a "translog" index. Other index number formulas (such as Fisher's ideal index) are exact for alternative functional forms. Various index numbers could therefore be employed. Diewert has defined an index number as *superlative* if it is exact for an $F$ which can provide a second-order approximation to an arbitrary linear homogeneous function. He introduces an entire family of superlative index numbers, and shows that the Törnqvist index belongs to this family; the Paasche and Laspeyres indices do not, however, belong. The implication of Diewert's results is that productivity researchers may be well advised not to use the restrictive Paasche or Laspeyres indices, and instead employ one of the superlative index numbers such as the Törnqvist (translog) or Fisher ideal index.

Although the translog index used by GJ has attractive properties for indexing TFP, it also suffers slightly from several drawbacks. First, in their computations, GJ use translog quantity indices; implicit price indices are computed by dividing value by the translog quantity index. All the GJ results would be altered slightly if they initially computed a translog price index and then computed the quantity index implicitly by dividing value by translog price index. This occurs because the translog index satisfies the factor reversal test only approximately. The implication is that if GJ had done all the necessary computations, they would have observed that $\partial \ln G/\partial t \simeq -\partial \ln C/\partial t$—the equality would not have held exactly, but only approximately.

4. This discussion is largely based on Diewert (1976).

Secondly, although the continuous Divisia index is reproducible (i.e., a Divisia index of Divisia indices is itself a Divisia index), the translog approximation does not in general possess this property.[5] Thus, if GJ first compute a capital index as a translog index of diverse capital inputs, then compute a labor index as a translog index of diverse labor input characteristics, and then finally compute total primary inputs as a translog index of the translog capital and translog labor inputs, they would obtain a different number than if in a single step they had computed total primary input as a translog index of all the diverse capital and labor inputs. The difference, I suspect, is in most cases likely to be very small if not negligible.

In summary, a significant contribution of the GJ paper is that it provides an explicit, rigorous theoretical foundation for the measurement of TFP. Several issues remain, however. First, since TFP is indexed essentially as a residual ($\dot{Y}/Y - \dot{X}/X$), anything not explained by changes in real factor input is attributed to technical change. Producer errors in optimizing behavior, departures from constant returns to scale, and errors in data measurement all become components of TFP. It would be useful to have a discussion on some of these issues. In particular, it should be possible to derive analytically the effect of TFP on errors in optimizing behavior and departures from constant returns to scale.

Secondly, the GJ theoretical discussion suggests that an interesting empirical extension would be to use econometric techniques and to test whether in fact TFP is an empirically meaningful notion. To do that, one would want to estimate the parameters of a flexible multiple input, multiple output transformation function and then use statistical inference to test for the validity of hypotheses relating to (i) homothetic or homogeneous additive separability of inputs from outputs, (ii) constant returns to scale, (iii) the existence of "labor," "capital," or "primary factor" composite indices,[6] and (iv) various forms of technical change (e.g., factor augmenting, Hicks-neutral, Harrod-neutral, Solow-neutral,

5. Diewert has shown that the Törnqvist (translog) index is reproducible if and only if the "true" subfunctions and the "true master" functions are linear homogeneous translog.

6. A procedure for testing separability restrictions using the translog production or cost functions has been developed by Berndt and Christensen (1974). There are, however, two problems with this approach. First, if one interprets the translog functions as a function in its own right, one can only impose separability conditions on the translog by simultaneously imposing additional restrictions on the separable subfunction; thus, if this separability restriction is rejected, one cannot at present determine whether the separability or the unavoidable additional restrictions "caused" the rejection. For further discussion, see Blackorby, Primont, and Russell (1977). An alternative procedure is to treat the translog as an approximation to the "true" function, and then test for separability at the

or Leontief-neutral). If (iii) were followed, evidence would be available on whether the notion of labor productivity, capital productivity, or primary factor productivity could be justified on the basis of appropriate separability restrictions. Incidentally, it would be particularly interesting to test whether the value-added notion of productivity is justified; recent evidence accumulated in my research suggests that the data in U.S. manufacturing may not be consistent with value-added restrictions (Berndt and Wood 1975).

Let me now turn to a second major contribution of the GJ paper—the discussion on labor *quality*. GJ devote a major portion of their paper to the construction of labor indices. Since labor is heterogeneous, and since numerous compositional and work-related changes have taken place over time, it is important that the composite index reflect the net effects of these changes. For each of the fifty-one industries, GJ decompose labor input into 1600 cells—eight age groups, ten occupational categories, five educational attainment levels, two sexes, and two employment categories. Since this is done for twenty-seven years in each of fifty-one industries, the total number of labor cells is 2,203,200—although many cells are empty. To do this, data from a number of sources—primarily the decennial census and the annual current population survey—are utilized. Since household and establishment totals frequently do not agree, extensive use is made of the suitably generalized RAS method. This raises the issue of how much error is introduced into the labor quantity and quality figures through the widespread use of the generalized RAS multiproportional adjustment method. Although GJ have gone to extraordinary lengths to employ all possible reliable data, one cannot help but question the reliability of the resulting labor quality and TFP measures. In an earlier paper (Jorgenson 1966), Professor Jorgenson has expended some effort discussing the sensitivity of measured TFP to errors in the construction of capital price data. At this point, some Monte Carlo–type research on the effects of measurement errors on computed TFP appears to be a useful direction for further research.

GJ attempt in their analysis to measure hours worked rather than hours paid for; the reason is that hours worked rather than hours paid for enters as an input into the production function. Hours paid for enters indirectly through the price of labor viewed from the vantage of

point of approximation (expansion). This procedure has been advocated by Christensen, Jorgenson, and Lau (1975). The problem with this approach is that the test results will vary with the data point chosen as the point of approximation (expansion), and thus this procedure could lead to inference which lacked robustness.

the producer, for price per unit of labor worked is computed as wage bill plus supplementary benefits (including paid holidays and employers' contributions to social insurance—an increasing portion of wages and salaries) divided by actual hours worked. GJ introduce and implement procedures on the measurement of hours worked which reflect an unusually thorough and detailed effort in measuring labor input. I suspect, however, that a number of errors still remain; in particular, the accuracy of census data on number of hours worked by "white-collar" workers, and the representativeness of the survey week in the context of the entire year are potential sources of considerable error.

The GJ indexing procedure for measuring labor input is valid of course only if the weights (cost or value shares) accurately reflect logarithmic marginal revenue products. Departures from this will introduce errors into the calculations. If, for example, employers invest firm-specific training in their workers, then marginal revenue product may be greater than wage paid, because the firm will want to recoup a share of its investment. In the present context, this may introduce considerable error into the time series data for certain white-collar occupational groups. Although a bit out of context, it is of interest to speculate on the effects of wage discrimination against women on measured productivity. If women have been paid wage rates less than their marginal revenue product, then postwar increases in the labor force activity of women have been weighted by downward-biased shares; measured total factor input then understates true total factor input, and measured TFP is biased upward. Alternatively, other things being equal, if discrimination against women declines, *measured* (but not necessarily actual) TFP will likely fall.

Let me now move on to capital input. GJ devote considerable care to the development of capital data, along with their extensive discussion on labor data. Remarks made above concerning labor quality indices carry over of course for capital quality. GJ are forced for data reasons to make several important assumptions. First, the assumption of *exogenous geometric decay* is made for all equipment and structures. There is some evidence to suggest that this assumption may not be unrealistic for certain types of equipment; on the other hand, the assumption appears less justifiable for other assets such as nonresidential structures. Further, recent events with respect to energy prices suggest that we may want to develop theoretical frameworks which make rates of decay, scrapping, and obsolescence endogenous and variable, rather than exogenous and constant. Second, GJ assume that in any given year the nominal rate of return is the same across assets in each industry, but that this common rate of return varies across industries. There may in fact be data reasons for doing this, but these are not discussed by GJ.

Third, GJ compute real capital input as a translog index of producers' durable equipment, nonresidential structures, land, and inventories. Working capital is not included; indeed, the issue of whether money ought to enter the production function and therefore enter the accounts of TFP is not discussed. Further consideration of this issue would be useful.

The final substantial contribution of this study is the introduction of intermediate goods into the detailed productivity calculations. Although the inclusion of intermediate goods might appear novel, in fact Vernon W. Ruttan already concerned himself with such issues in the early 1950s.[7]

Appropriately, GJ first address themselves to the issue of why intermediate materials ought to be included in the calculation of TFP. Their answer is straightforward and convincing: the measurement of TFP is based on the theory of production behavior; to a producer, intermediate inputs are treated symmetrically with all other inputs. The cost-minimizing firms will choose that set of capital, labor, and intermediate inputs which minimizes total cost given output. Therefore intermediate inputs, along with capital and labor, should enter in the calculation of TFP.

One of the reasons researchers have ignored intermediate inputs in many previous empirical studies is that a large portion of American studies have been done at the national level, and at the national level almost all intermediate transactions except imports and exports "cancel out"; thus, failing to include intermediate inputs in the aggregate American studies involved neglecting a relatively small amount (imports minus exports accounted for about 5% of U.S. gross national product) of transactions. At the industry level, however, intermediate inputs are quite important.

Apparently it still is not widely known that for a single industry TFP measured using value-added techniques will generally be greater than or equal to TFP measured using gross output. This significant inequality relationship seems to have been discovered several times. In his 1954 U.S. Department of Agriculture Marketing Research Report,[8] Vernon W. Ruttan discusses the value added–gross output relationship at some length, and attributes the TFP inequality discovery to an un-

7. See Vernon W. Ruttan, "Technological Progress in the Meat Packing Industry, 1919–1947," Ph.D. dissertation, Department of Economics, University of Chicago, 1952; this thesis was published in abridged form under the same title as United States Department of Agriculture Marketing Research Report No. 59, January 1954. Also see the article by Ruttan, "The Contribution of Technological Progress in Farm Output," *Review of Economics and Statistics* 38 (February 1956).

8. See previous note.

published (and apparently undated) paper by Herbert A. Simon.[9] The same inequality was derived independently in 1961 by Evsey Domar, was discovered once more by Spencer Star in 1974, and then was generalized by Charles Hulten in 1974. Hence discussion of the implications of using intermediate inputs in growth accounting has a rather extensive lineage.

There is one issue regarding intermediate inputs, however, which remains troublesome. In his 1961 paper Domar noted that the measure of TFP depends critically on what one means by an intermediate input. Suppose one computes TFP and includes in a sector's outputs and inputs sales of one firm in the sector to another firm in the same sector; call this "double counting" version $TFP_1$. Suppose that another researcher computes $TFP_2$ excluding these intrasectoral transfers but including all intersectoral sales. Domar showed that $TFP_1 < TFP_2$. A further contribution of the Domar paper was the development of a measure of TFP with intermediate inputs that was invariant to how one defined intermediate inputs, i.e., how one disaggregated a sector. Unfortunately, this aspect of TFP measurement has not been discussed by GJ, nor have alternative TFP measures been presented. As a result, comparison among sectors is very difficult. I submit that the issue of invariant measures of TFP in the Domar sense ought to be high on the list of future research priorities.[10]

Finally, on page 111 GJ address themselves to the important issue of how capital data might be adjusted to reflect more accurately the amount of capital services actually utilized. The interested reader will remember that this issue of "adjusting for utilized capital" over the years has been a contentious one in the productivity measurement debates between Jorgenson and Griliches and Denison. In the present context, GJ measure total factor input in such a way that variations in energy consumption are included in the productivity calculation. This leads GJ to conclude that "no further adjustment of capital input or intermediate input is required" (p. 112). The principal feature of the GJ procedure here is that for given real capital, labor, and nonenergy intermediate material input, measured total factor input will vary with energy usage, and thus measured total factor productivity will be affected by variations in energy demand. Note, however, that measured

9. Ruttan's citation is as follows: Herbert A. Simon, "Some Models for the Study of the Economic Effects of Technological Change," Cowles Commission Discussion Paper 213 (unpublished).

10. It follows, of course, that at the aggregate national level international comparisons of TFP are practically meaningless unless exports and imports are fully incorporated; if these intermediate inputs are neglected, other things being equal, countries with relatively larger foreign sectors can be expected to show greater TFP growth.

real capital input is completely independent of energy usage; variations in energy expenditures in no way alter measured real capital input.

In my judgment, the GJ procedure of this paper is clearly preferable to the practice whereby capital is adjusted using some type of relative electricity capacity index, e.g., actual electricity consumption divided by nameplate capacity. The latter procedure not only is confined solely to electricity and raises measurement issues in how one defines "capacity," but also assumes that the relationship between capital and energy is one of strict proportionality. In contrast, the GJ technique treats energy just like any other input, and does not make any assumption on whether the relationship between energy and capital is one of substitutability, strict proportionality, or complementarity.[11]

Let me now conclude my comments with some suggestions for further research and with a few remarks on the productivity measurement debates. The recent developments in productivity measurement have occurred simultaneously with a very substantial set of developments in the theory of production. In particular, we now have moved far beyond the restrictive two-input, single-output Cobb-Douglas, and CES production models and instead deal with multiple-input, multiple-output "flexible" or generalized functional forms. We have also recently witnessed the revival of index number theory which relates closely to the "flexible" production models. These index theory results suggest that we no longer should use fixed-weight Paasche or Laspeyres indices, but should rather use the chained ideal Fisher or chained translog indices. In both cases, we have made substantial progress by generalization. I personally would like very much to see the theoretical underpinnings of TFP measurement generalized from zero profits, perfect competition, constant returns to scale to zero profit, monopolistic competition, and possibly increasing returns to scale. There appears to be some evidence that at the establishment or two-digit level, slightly increasing returns to scale occur—although it should be pointed out that all the studies have, I believe, been based on value added rather than gross output functions. The reason we have so frequently assumed constant returns to scale and perfect competition is for convenience in data construction and in the establishment of national real and financial accounting frameworks. It appears to this reader that the zero-profits assumption is rather crucial, but that data construction and consistent accounting frameworks could be derived under monopolistic competition with zero profits and increasing returns to scale. One other additional area for further research is the incorporation of dynamic ("disequilibrium" or

11. For a development of the energy-capital and "utilized capital" discussion, see Berndt and Wood (1977).

"temporary equilibrium") considerations into the theory of production, cost, and the measurement of TFP.

In summary, this paper embodies many of the recent developments in the theory and measurement of productivity; a number of issues, however, still remain. Let us suppose that these remaining issues were resolved; that would, of course, constitute a noteworthy accomplishment. Where would we then stand? I am reminded of the statement, "Understanding the atom is child's play compared with understanding child's play." In the present context, where we still need an enormous amount of research effort is in the area of why and how productivity gains are realized; how can we adequately model the costly process of innovation, implementation, and technical change? How are these processes affected by market structure? How is the rate and bias of technical change affected by changes in relative prices? How is technical change transferred among countries through international trade? Cynics might argue that it is possible that economists will agree on how to measure productivity long before we will understand why and how it takes place.

One final comment. You probably have noticed that in these comments I have not mentioned ways in which the GJ approach differs from the procedures adopted by Edward Denison and John Kendrick. I believe the present paper offers a clue as to why these researchers differ. As I read the lengthy debate carried on by Griliches, Jorgenson, Christensen, Gollop, Denison, and Kendrick, I am struck by the following: Although there are substantial differences in details, Griliches, Jorgenson, Christensen, Gollop, and frequently Denison essentially agree on what they want to measure—namely, real output and real factor input, including all quality changes. From the vantage of this reader, however, Kendrick has something different in mind than the task of accounting for real outputs and real inputs. The reason Kendrick does not adjust labor and capital for quality changes may well be that Kendrick has a more profound notion in mind—that of measuring changes in "welfare" over time; for example, Kendrick appears to be interested in how "well off" the worker is, how much output on average the worker will obtain for a measured man-hour of input. Such a welfare notion is of course extremely difficult to measure, and could provide material for endless debates and conferences. But then the argument of which approach is "right"—Griliches, Jorgenson, Denison, or Kendrick—may well be misplaced. When researchers are attempting to quantify different notions, it is not surprising that they fail to agree on methods of measurement. Perhaps the most important contribution of the present GJ paper is that it clearly and rigorously defines the concept of TFP and then proceeds with a detailed and careful implementation.

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