ensure that this resource remains available for future generations by using fishing methods that are economically sound and environmentally sustainable.

SEE ALSO *Developing Countries; Industry; Technological Progress, Economic Growth; Tragedy of the Commons*

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SEE *Campbell, Donald.*

FIXED COEFFICIENTS PRODUCTION FUNCTION

A production function associates the maximum level of output producible with given amounts of inputs. If the inputs must be combined in fixed proportions, like the ingredients of a recipe in a cookbook, the function is a fixed coefficients production function. It is also called a Leontief function, after its inventor, the economist and Nobel Prize winner, Wassily Leontif. Call centers require a one-to-one proportion between workers and telecommunication equipment. Denoting the input quantities by L and K, the isoquants are L-shaped (with the kink on the 45 degree line).

To introduce the formal definition, denote the quantities of inputs required per unit of some output by $a_1, \ldots, a_n$, where n is the number of inputs. These so-called input coefficients constitute the recipe or technique for the production of the output considered. Denote the available

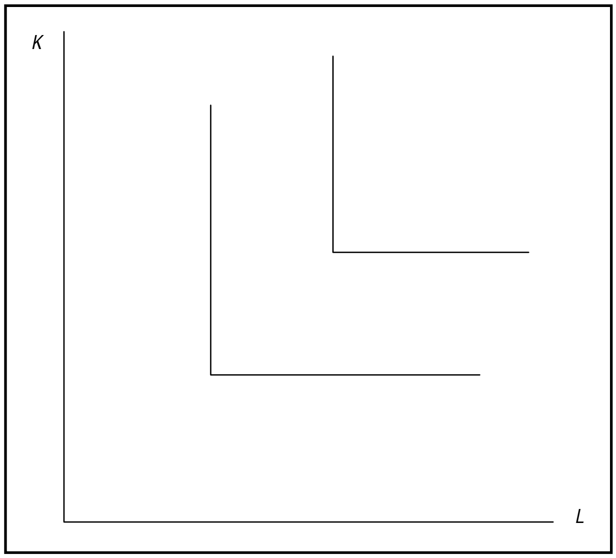

Figure 1

amounts of inputs by $x_1, \ldots, x_n$, respectively. Then the attainable level of output is given by $y = \min \{x_1/a_1, \ldots, x_n/a_n\}$. This is the defining formula of the fixed coefficients production function. The inputs for which the minimum value is assumed are called the bottlenecks.

The fixed coefficients production function is the cornerstone of input-output analysis, the quantitative economic tool developed in 1936 by Leontief, who traced the origin to Francois Quesnay's *Tableau Économique* of 1758. Scholars Heinz Kurz and Neri Salvadori described the roots of input-output analysis in detail in their 2000 work, and the theory is exposited in Thijs ten Raa's *Economics of Input-Output Analysis* (2005). The fixed coefficients function is popular, because only a single observation is needed to calculate it, making use of the input coefficients $a_i = x_i/y$. The connection between fixed coefficients and input-output analysis is as follows.

Since inputs are produced (such as electricity) or nonproduced (such as labor services), we may label them $1, \ldots, m, m + 1, \ldots, n$, where the last $n - m$ inputs are the nonproduced or so-called factor inputs. Denote the input coefficients of output j by a_{ij}. The matrix of intermediate input coefficients is $A = (a_{ij})_{i,j = 1, \ldots, m}$ and the matrix of factor input coefficients is $B = (a_{ij})_{i = m+1, \ldots, n, j = 1, \ldots, m}$. The matrix of factor input coefficients gives the direct factor requirements of products. Post-multiplication of B with the so-called Leontief inverse, $(1 - A)^{-1} = 1 + A + A^2 + \ldots$, yields the matrix of total factor requirements or factor contents of products. The total requirements include the factor requirements of the produced inputs, BA, the factor requirements of the produced inputs of those inputs, BA^2, etcetera.

An important application is the Marxian theory of labor values, in which all commodities are produced, directly or indirectly, by labor. Then the factor input coefficients matrix B reduces to a row vector of direct labor coefficients and the total requirements becomes a row vector of labor contents, one for each product. Another application is energy economics. Here the direct coefficients measure the energy used per unit of output and the total coefficients measure the total amount of energy embodied in products. The inclusion of the indirect effects may cause reversals in the energy intensity of products, when the production of an output requires little energy, but much intermediate input of which the production is energy intensive. The inclination of politicians to subsidize goods of which the direct energy requirements are low may therefore be ill conceived.

Input coefficients tend to be fixed at the level of the firm. Indeed, managers know how many workers are needed to operate the machines. Input coefficients vary between firms though and, therefore, the fixed coefficients production function is less appropriate for industries or economies. For example, if the wage rate increases relative to the rate of interest, labor-intensive firms may shut down and capital-intensive firms may expand to full capacity. As a result, the economy will be more capital intensive. Though derived from micro fixed coefficients production functions, the macro production function will thus feature input substitutability, much like the Cobb-Douglas function. In fact, the latter can be derived mathematically if the production capacity across firms follows a Pareto distribution, which is defined by the same formula as the Cobb-Douglas function. Most applied general equilibrium models feature production functions with a mixture of fixed and variable coefficients, but even when all the production functions are of the fixed coefficients variety, the response to price shocks may be the same as in a model with variable coefficients production functions.

SEE ALSO *Input-Output Matrix; Leontief, Wassily; Production Function*

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Thijs ten Raa

FIXED EFFECTS

SEE *Generalized Least Squares.*

FIXED EFFECTS REGRESSION

A fixed effects regression is an estimation technique employed in a panel data setting that allows one to control for time-invariant unobserved individual characteristics that can be correlated with the observed independent variables.

Let us assume we are interested in the causal relationship between a vector of observable random variables $x = (1, x_1, x_2, \ldots, x_K)'$ and a dependent random variable y where the true linear model is of the following form:

$$y_i = \beta' x_i + \mu_i + \varepsilon_i \text{ with } i = 1, \ldots, N$$

with μ being an unobserved random variable characterizing each unit of observation i and ε the stochastic error uncorrelated with x.

When μ is correlated with x we cannot consistently estimate the vector of parameters of interest β using Ordinary Least Squares because the standard assumption of no correlation between the error term and the regressors is violated. In a cross-sectional setting, typical strategies to solve this omitted variable problem are instrumental variables or the inclusion of proxies for μ. However, when the available data is longitudinal, that is, when it contains a cross-sectional as well as a time series dimension, it is possible to adopt alternative estimation methods known in the literature as "panel data" techniques.

Assuming we repeatedly observe N units for T periods of time, and that the unobservable variable μ is time invariant, we can write our model as:

$$y_{it} = \beta' x_{it} + \mu_i + \varepsilon_{it} \text{ with } i = 1, \ldots, N \text{ and } t = 1, \ldots, T$$

Depending on the correlation between the omitted variable μ and the regressors x, alternative estimation techniques are available to the researcher. A fixed effects regression allows for arbitrary correlation between μ and x, that is, $E(x_{jit}\mu_i) \neq 0$, whereas random effects regression techniques do not allow for such correlation, that is, the condition $E(x_{jit}\mu_i) = 0$ must be respected. This terminology is somehow misleading because in both cases the unobservable variable is to be considered random. However, the terminology is so widespread in the literature that it has been accepted as standard.

A fixed effects regression consists in subtracting the time mean from each variable in the model and then estimating the resulting transformed model by Ordinary Least Squares. This procedure, known as "within" transformation, allows one to drop the unobserved component