An Empirical Examination of Factor Substitutability

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Summary: This paper looks at the issue of factor substitutability versus complementarity from the point of view of directional causality. That is, prior to estimating a production function, is there any empirical support for the belief that capital, labor, energy and materials are substitutes or complements for one another in the production process? The results suggest that capital is a substitute for the other factors of production but when the other factors are compared pairwise, such a conclusion does not follow.

Introduction

Recent years have seen a renewed interest in the study of factor substitutability and complementarity in the production process. A myriad of inputs typically enter a firm's production process. Since a firm tends to choose that bundle of inputs that minimizes the total cost of producing a given level of output, the derived demand for inputs depends on the level of output, the substitution possibilities among inputs allowed by the existing technology and the relative price of the inputs.

One important impetus for looking more intensively at factor substitutability/complementarity has been its potentially profound impact on the production process and the attendant implications for employment [Branson, 139-144]. To the extent that energy has no substitutes then a reduction in its availability will result in inflation and a significant reduction in the level of employment. In this regard the impact of the Arab Oil Embargo on the United States economy in the 1974-1975 period is still not well understood because the relationship between factor inputs in the production process are not well understood. A large number of studies exist purporting to measure the degree of factor substitutability and complementarity using time series data, cross-section data, and pooled data. Berndt/Wood [1975, 1979] provide a nice summary of the findings and the interested reader is referred to these articles. The most interesting result of these studies is the contradictory evidence regarding substitution possibilities in general and substitution possibilities between energy and capital in particular.

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It has been suggested that the conflicting evidence might be explained by a number of reasons including differing data sets and approaches to measuring factor input quantities and prices, varied treatment of excluded inputs and distinctions between short-term and long-term elasticities. One explanation that has not been offered is that the estimates are so imprecise that they are picking up spurious relationships. That is, while the estimates show a substitution relationship, for example, between energy and capital, de facto no relationship exists — i.e. capital is not substitutable for energy. The implication of this is simply that a Leontief-type fixed coefficient production function would be a more appropriate representation of reality. What this issue reduces to is whether there is directional causality between the quantity of one factor and the price of another. Before providing any empirical investigation of this, a concise exposition of the theoretical rationale for anticipating changing factor intensities in the production process and a general discussion of directional causality are provided.

Theoretical Foundations

Consider the following example. Assume that a cost minimizing competitive firm is initially in equilibrium with output at some equilibrium level and that the firm possesses a positive, twice differentiable strictly concave production function with four inputs (capital, K, labor, L, energy, E, and materials, M). Next, assume that the price of one of the factor inputs changes relative to the others (e.g., the price of energy rises). The total effect of this on the demand for the other factors can be decomposed into two parts. First, there will be the gross substitution effect resulting in a reduction in use of the factor with the higher relative price and an increase in the use of the other factors (note that this will always be the case — less of the input whose price increased and more of the other inputs [Henderson/Quandt, p. 70]. Second, there will be an expansion effect which is just the difference between the total effect and the gross substitution effect where the total effect of such a price change results when the output of the production function is held constant and all inputs adjust to their new cost-minimizing levels. The magnitude of the expansion effect is dependent, of course, upon the marginal products of the factors of production [Johansen]. It is possible for the expansion effect to dominate the gross substitution effect with the result that one actually observes an increase in the use of the factor having the initial price increase. That is, it is possible that factors of production are gross substitutes but net complements. Whether net substitutability or complementarity exists depends on whether the gross substitution effect or the expansion effect is dominant. This is an empirical issue. What is of relevance now is the extent to which one can sort out these effects. A myriad of techniques exist to allow for such a determination. In other words, a large number of specifications are available that permit the estimation of elasticities of substitution for the factors of production. These specifications necessarily presuppose that the assumptions concerning the nature of the production function are correct. It need not be the case, however, that the factors of production are substitutable in the fashion assumed because the technology involved in the production process is prohibitive. Consequently, before hypothesizing a specific form of the production func-