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THE EFFECT OF ENERGY SUPPLY ON ECONOMIC GROWTH
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The Effect of Energy Supply on Economic Growth

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THE EFFECT OF ENERGY SUPPLY
ON ECONOMIC GROWTH

by

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CHAPTER ONE

Introduction

This thesis describes the structure of a multi-sectoral, general equilibrium growth model of the U.S. economy that gives special attention to the energy sectors and presents results from the simulation of this model under varying conditions of energy supply.

A major characteristic of the U.S. economy has been its growth in real output. From 1900 to 1970 real production increased at an annual rate of 3.3%, amounting to a nine fold increase. During the same period per capita output grew at a rate of 1.8%. The benefits of this growth are obvious. It brought great benefits in the form of higher material living standards for people throughout the income distribution. There is now increasing concern that it cannot continue.

One example of the expression of this fear is in a recent article by Robert L. Heilbroner, "Middle-Class Myths, Middle-Class Realities," [23, p. 41] which states,

But growth is a process whose days are numbered, partly because of a shortage of resources, partly because of pollution dangers. Probably within our lifetime, certainly within that of our children, growth will have to be throttled back.
In the neo-classical theory of economic growth, the rate of growth in output is the sum of the rates of growth of labor input and labor productivity. This result is based on constant costs in production. The problem is that some sectors of the economy experience increasing costs of production, namely, those which fashion primary products from depletable resources. The issue is the effect of rising costs in the production of some commodities important for economic activity on growth. To study this problem an analytical framework is needed that will incorporate the effect of increasing costs in some sectors at the microeconomic level on the process of aggregate economic growth.

In the study of this problem, the interactions between sectors in the supply of intermediate inputs to each other as well as their mutual competition in the factor market necessitates a general equilibrium context. That the competition for some factors such as capital take place over many time periods necessitates a dynamic context as well. The framework developed here can be used to study the impact of increasing costs in individual sectors on aggregate growth, or to study the effects of bottle-necks in particular sectors on aggregate supply.

When discussing a change in conditions of energy supply it is important to distinguish between changes in
the supply of international and domestic energy. The action by OPEC has shifted upward the supply curve of energy obtained in international markets. In the domestic energy market, however, the basic supply relationship has not changed. Unless there are barriers to trade, the price of energy in domestic and international markets must be the same, and the change in the world price of energy has forced domestic production up along the pre-existing domestic supply curve so that the marginal cost of domestic energy is equal to the world price of energy.

Between 1951 and 1973, real GNP in the U.S. grew at an annual rate of 3.5%. Employment grew at 1.6% during the same period implying a rate of increase in productivity per worker of 1.9%. Energy has been available throughout this period at declining real prices; between 1950 and 1970 total use of energy in the U.S. increased from 34.1 quads (quadrillion Btus) to 68.8 quads, an annual rate of growth of 3.6%. With the oil embargo and the quadrupling of oil prices by OPEC in 1973, the assurance of supply and the long term decline in energy prices stopped. Because energy use is pervasive in economic activity, the effect of this change in the energy situation on the economy is an important issue.

While the primary goal of this thesis is to analyze the effect of energy supply on economic growth, it also
presents a new methodology for approaching this kind of problem. The tool of analysis is a general equilibrium growth model. While theoretical multisectoral general equilibrium growth models have been developed before, this is the first empirically oriented model with endogenously determined non-malleable capital stocks. The sectoral composition by industry closely mirrors the U.S. economy as does the breakdown of final demand into consumption, investment, government, and net exports. The dynamic relationships allocating capital among the different sectors are empirically determined.

Because this model is empirically oriented it must address the solution of nonlinear general equilibrium systems. An algorithm for solving such models is presented in an appendix for chapter 3.

It should be noted that this analysis is general and not limited to the study of energy and economic growth. The same approach can be used to model the effect of changes in the supply of any produced raw material on economic growth.

We now describe the model and some of its features. At the microeconomic level the model solves for market clearing prices for nine produced goods, labor and the market clearing quasi rents for nine sector-specific capital stocks. The nine produced goods are:
1. agriculture, mining and construction
2. manufacturing
3. transportation
4. services
5. coal mining
6. oil and natural gas production
7. petroleum refining
8. electric utilities
9. gas utilities.

These are the sectors used by Hudson and Jorgenson in their study, "U.S. Energy Policy and Economic Growth, 1975-2000," [28]. The first four sectors can be classified as non-energy material goods and services, and the remaining five are energy goods. The nine separate capital goods in the factor market must be distinguished because of the assumption of non-malleability of capital. Once investment in the capital stock of a particular industry has taken place it cannot be moved to provide productive services to some other industry. While the allocation of the capital stock between sectors is fixed, the allocation of labor between sectors can change. In the short run, there are diminishing returns to labor inputs for all sectors.

Prices of the produced goods are equal to their unit costs, which equal the sum of the unit value added and unit intermediate input costs. Intermediate input
requirements are determined through an interindustry input-output system. Income is equal to the value added which is equal to total expenditure. Total expenditure is allocated between consumption, investment, government, and net export spending. The simultaneous solution of these features satisfy conditions for general equilibrium.

The dynamic aspect of the model allocates new capital to the different industries on the basis of their individual demands for capital. Technical progress is of the autonomous Harrod-neutral variety. The rate of growth of the effective labor force, which is the sum of the rates of growth of physical units of labor and the rate of growth in labor productivity, is exogenous to the model. Energy supply enters the model through effects on the production functions for domestic energy and through the payment of produced goods to foreigners in exchange for imported oil.

When the conditions governing supply of a commodity deteriorate the price of the commodity will rise. A market economy can be expected to respond to the increased price in four ways. First, the increase in price will cause the prices of the goods that it is used to manufacture to rise and thus discourage their use and motivate final consumers to find substitutes that use less of the scarce commodity. Second, producers trying to maximize profits will attempt
to minimize use of the scarce commodity in production. Third, profitability of producing the scarce commodity will rise, inducing more resources to be devoted to its production. Fourth, more effort will be devoted to developing new processes and techniques that will facilitate the first three responses over time.

Clearly, the fourth response, technical innovation, is the most difficult to predict or to model. The response of consumers and producers is also difficult to measure in a detailed model. For these reasons the model developed here concentrates on the third response, the devotion of more resources to the production of the scarce commodity. The model assumes that there will be little price induced substitution by consumers and producers. To the extent that there is substitution, the model will over-estimate the effects of scarcity. Over long periods of time neither these substitution responses nor the technical change response can be ignored. For this reason this model concentrates on the intermediate term effects on growth.

It should be emphasized that this model, like all growth models, is essentially a supply model. There is no monetary sector, so that prices are in relative terms with the wage rate as the numeraire. It is assumed that monetary and fiscal policy will maintain adequate aggregate demand so that real output will be equal to potential GNP.
Chapter 2 surveys the recent literature on energy and economic growth. In chapter 3 the analytical model is presented. The dynamic aspect of the model depends on the investment function developed and estimated in chapter 4. Chapter 5 presents the numerical assumptions and the simulation results.
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