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CONSISTENT PROJECTIONS OF ENERGY DEMAND AND AGGREGATE ECONOMIC GROWTH: A REVIEW OF ISSUES AND EMPIRICAL STUDIES

by

Ernst R. Berndt and David O. Wood

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Mr. Berndt is Associate Professor of Economics at the University of British Columbia, and is a resource group member of the Demand-Conservation Panel, CONAES. Mr. Wood is Senior Lecturer at the M.I.T. Sloan School of Management and Associate Director of the M.I.T. Energy Laboratory, and is a member of the Synthesis Panel, CONAES.

PREFACE

This paper has been prepared at the request of and for the Demand-Conservation Panel (Chairman: John H. Gibbons) of the National Research Council Committee on Nuclear and Alternative Energy Systems (CONAES). The views expressed are the sole responsibility of the authors, and should in no way be construed as reflecting the official views or positions of the Demand-Conservation Panel or of the CONAES. The constructive comments of Professors Duane Chapman, William Hogan, Dale Jorgenson, and Timothy Mount are acknowledged.

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I. INTRODUCTION

How to treat the relationship between the demand for energy and aggregate economic growth has been a difficult question for energy analysts. The crux of the difficulty is that energy is always used in combination with other factors to produce an energy-related service or product. Thus, when analyzing or projecting energy demand, it is necessary to take account of the interaction between the bundle of inputs actually demanded and the composition and level of output produced.

Until recently energy demand studies have not attempted to model explicitly these interactions. Instead, analysts have relied on simplifying assumptions. One approach has been to assume that the amount of energy required to produce a given level of output is completely dependent upon that level. For example, if one assumes that total BTU's required to produce a given level of output, say GNP, are related by a constant α, then

$$\alpha = \frac{\text{Total BTU's}}{\text{Real GNP}}$$

and one may forecast total energy demand at some future date simply by estimating α and projecting real GNP. In some cases α is assumed to be time-trended. A troublesome aspect of the total dependence assumption is that it ignores price-induced compositional changes in GNP, as well as other inputs such as capital, labor, and non-energy intermediate factors of production.[1]

The alternative simplifying assumption to total dependence is total independence. With this assumption, one projects energy demand and economic growth separately, implying that alternative energy demand projections are consistent with a single GNP projection. This assumption is also troublesome since it is not clear what is implied about changes in non-energy inputs such as capital and labor.

Recent advances in modeling and estimation procedures permit examination of the interactions among energy and non-energy inputs, as well as of the simultaneous effects upon the composition and level of output. The purpose of this paper is to review the analytical and empirical evidence relating to alternative hypotheses, including but not restricted to the total dependence and total independence assumptions.

In Section II a conceptual framework is presented; in Section III the relevant empirical evidence is reviewed, and in Section IV implications for CONAES are outlined.

II. A CONCEPTUAL FRAMEWORK

A. Introduction

It is well known that the "total dependence" method of projecting energy demand via constant or time-trended energy-GNP coefficients assumes that derived demands for all factors of production are independent of input prices.[2] This assumption implies, therefore, no substitution possibilities among the various factors of production, including energy. The fixed coefficient Leontief formulation would be one example of a model reflecting this assumption.

The extreme alternative to zero substitution would, of course, be perfect substitution. In this instance, the choice of production technology is perfectly flexible. A change in the conditions of availability of one factor, say energy, will be exactly offset by changes in the usage of other factors with no effect upon output and production costs. Thus, the relation between any one factor, say energy, and output is perfectly flexible.

The CONAES approach to the issue of the relation between energy demand and economic growth tends in the direction of assuming substantial substitution possibilities between energy and other inputs so that significantly different energy demands are assumed consistent with a single given level of output. The procedure has been to construct scenarios in which the aggregate rate of growth in GNP is specified exogenously.[3] Within the context of these alternative scenarios, consistent estimates of energy consumption and, in some analyses, prices by major consuming sectors and energy types have been projected. These projections have been made using both formal and judgmental models of the energy system. The combined results are alternative energy consumption projections consistent with a single growth rate in real aggregate GNP.

For present purposes, we note that in order for alternative energy consumption levels and prices to be consistent with a single time path for real output, it must be the implicit assumption that substantial substitution possibilities exist among outputs and between the energy and non-energy factors of production.

B. Demand for Energy

Perhaps the most obvious characteristic of energy in all its various forms is that it is always an intermediate good, used in combination with other goods and services to produce other intermediate goods or to produce services for final consumption. In either case, the demand for energy will be a derived demand depending upon such things as the level of the cooperating capital stock (producer and consumer durables, structures), the energy efficiency characteristics of this stock, the substitution possibilities among energy and the other factors of production, including capital, and the decisions of producers and consumers regarding the level and composition of services required.

Consider the following example. Suppose that for some reason the price of energy inputs rises while all other input prices remain constant, and that all economic agents realize that this price change is likely to be relatively permanent. The consequences of this price change may be separated into three types of responses: (i) In the very short run, the most important response is likely to be a reduction in the utilization rate of the existing capital stock in energy-intensive applications. (ii) In the short to medium term, the most significant responses are likely to be a reduction in demand for energy-intensive goods and services, and substitution of other factors of production to compensate for the higher priced energy, including such adjustments to the existing capital stock as are possible through retrofitting to improve energy utilization efficiency. (iii) As the time period for adjustment increases, however, opportunities to invest in more energy-efficient capital will be realized, or will be created by technological advance.

In the latter two cases, the energy efficiency of the production process will be increased in several ways. First, it may be possible to minimize the increase in production costs by choosing technologies which increase the relative mix of non-energy factors combined with a given stock of capital. For example, labor might be combined differently with capital of a given energy efficiency to reduce the actual demand for energy. Thus, there will be a reduction in the demand for the aggregate of capital and energy--a composite we refer to hereafter as "utilized capital"--and an increase in the demand for labor. Secondly, we would expect that the energy efficiency of utilized capital stock will improve through substitution of capital for energy. The length of time required to attain the optimal energy-efficient capital stock will depend upon the scrapping rate for the existing stock and the rate of new investment, both of which can be affected by federal tax policy.

In summary, then, the likely effects of a long-run increase in relative energy prices will be:

Very Short Term

- dominated by reduction in the utilization rate of existing capital stock, with possible corresponding unemployment of other inputs.

Short to Medium Term

- upgrading of the energy efficiency of the existing capital stock through retrofitting, constrained by the technical substitution possibilities between the existing capital stock and energy.
- substitution of other inputs for utilized capital, again limited by the technical substitution possibilities between utilized capital and other inputs.

Long Term

- dominated by changes in the energy efficiency characteristics of the aggregate capital stock as old capital is retired.
- substitution of other factors for the energy/capital (utilized capital) composite, as old capital is retired.
- development of new technologies to reduce total cost of producing a given service.

The extent to which the realization of these various substitution possibilities permits output and cost to return to previous levels is, of course, the crucial point respecting the assumption made in the CONAES study. Clearly, the greater the degree of substitution between energy and capital within the utilized capital composite, the greater the degree of substitution among utilized capital and other inputs, and the greater the extent of substitution in output composition, the more likely that in the long run previous output and cost levels will be attained, and therefore the more appropriate the CONAES assumption.

C. Framework for Empirical Analysis

Two extremes regarding substitution possibilities have been noted:

(i) zero substitution possibilities in both the short and long runs, implying both that the energy-capital composite (utilized capital) is used in fixed proportion with all other inputs, and that capital and energy are used in fixed proportions <u>within</u> the utilized capital composite; (ii) nearly perfect substitution possibilities[4] in the long run between energy and capital within the utilized capital composite, and nearly perfect substitution possibilities among utilized capital and other inputs. The former position permits energy forecasting by the total dependence procedure, while the latter position underlies the complete independence procedure employed by CONAES.

Recent developments in the economic theory of production and cost functions have stimulated a number of empirical studies of the relation between energy and non-energy inputs. Before presenting the results of these studies, we briefly summarize their common underlying analytical framework.

Consider a homogeneous of degree one production function relating the maximum possible flow of gross output (Y) to the input services of capital (K), labor (L), energy (E), and other materials (M).[5] The function can be represented as

(1) $$Y = Y(K, L, E, M).$$

In order to proceed with analytical and empirical discussions on the relationship between aggregate energy demand and aggregate GNP (value-added), it is necessary to specify a value-added formulation of (1). The concept of value added has been employed by national income accountants as a device for allocating the origins of national income to the services of capital and labor. Nominal value added is the product $P_V V$:

(2) $$P_V V = P_K K + P_L L$$

where V is real value added, P_V is the value added deflator, P_L is the price of labor services, and P_K is the after-tax price of capital services. The conditions under which it is valid to rewrite (1) as

$$(3) \qquad Y = Y_1(K, L, E, M) = Y_2[f(K, L), E, M] = Y_3(V, E, M)$$

are called conditions of <u>weak separability</u> of K and L from E, M;[6] hereafter we call the weak separability restrictions in (3) the conditions for GNP separability. An alternative but equivalent interpretation of the GNP separability condition is that substitution between the components of V -- that is, substitution between K and L -- must not depend on E and M. In terms of partial elasticities between inputs i and j, (denoted as σ_{ij}) GNP separability is valid if and only if[7]

$$(4) \qquad \sigma_{Ki} = \sigma_{Li}, \qquad i = E, M.$$

Hence the GNP separability condition can be interpreted as requiring that the components of value added (K and L) must substitute equally well with all other inputs.

In Section II.B the crucial importance of the energy-capital relationship was emphasized and the notion of utilized capital -- a composite index of energy and capital -- was introduced. It is therefore of interest to examine what the assumption of a utilized capital composite index implies. Analogous to the above discussion, it must be true that the utilized capital composite is well defined if and only if capital and energy are weakly separable from the other factors of production. If this is true, we can rewrite (1) as

$$(5) \qquad Y = Y_1(K, L, E, M) = Y_4[g(K, E), L, M] = Y_5(K^*, L, M)$$

where $K^* = g(K, E)$ is the utilized capital composite. In terms of restrictions on the partial elasticities of substitution, the utilized capital composite is well-defined if and only if

(6) $\sigma_{Ki} = \sigma_{Ei}$, $i = L, M.$

The equality restrictions in (4) and (6) can, of course, be tested statistically using econometric methods. The additional assumptions implicitly made by the total dependence (zero substitutability) and complete independence (virtually perfect substitutability) forecasting procedures are now considered.

In the case of total dependence (fixed proportions), the assumptions in addition to (4) are that

(7) $\sigma_{ij} = 0,$ $i, j = K, L, E, M.$

In particular, note that (7) implies

$$\sigma_{KL} = \sigma_{EL} = \sigma_{KE} = 0,$$

so that (7) is more restrictive than both (4) and (6).

The assumption of the various CONAES groups that GNP and energy are independent can also be interpreted as implicit restrictions on partial elasticities. In particular, the CONAES assumption implies not only (4), but also that σ_{KL}, σ_{EL}, σ_{KM}, σ_{EM} and σ_{KE} are positive and very large.

The previous discussion suggests that in reviewing the empirical results of studies of elasticities of substitution between energy and other factors of production, particular attention should focus on:

$$\sigma_{E,i} \quad \text{for any } i$$
$$\sigma_{(K,E),i} = \sigma_{K*,i} \quad \text{for any } i$$

together with statistical evidence on the existence of consistent indices of utilized capital and value added.

III. REVIEW OF EMPIRICAL FINDINGS

In this section a review of empirical evidence on substitution elasticities between energy and non-energy inputs is presented.[8] Several background comments are in order. First, the econometric studies are based on historical data -- in almost all cases, the data are post World War II through the early 1970's. Data from 1974 onward, when relative energy prices began to increase, have, to our knowledge, not yet been utilized.

Second, the econometric studies to date have, either explicitly or implicitly, made strong assumptions regarding the extent of competition and the absence of costs of adjustment. In particular, little empirical evidence is available on the dynamics of adjustment to higher priced energy. Undoubtedly, the assumptions of instantaneous adjustment embodied in the empirical studies are less than fully realistic. What is not clear, however, is how robust the published results would be to changes in these underlying assumptions.[9]

Third, the brief review we offer below deals with substitution between energy and non-energy inputs, but does not examine the literature on intra-energy substitution. For a recent review of such empirical studies, the reader is referred to Lester Taylor [1976] and the references cited therein.

Finally, most of the studies reviewed are based upon data for the manufacturing sector. Thus, excepting Hudson-Jorgenson [1974] and Hnylicza [1975] [1976], the studies reviewed provide no information relevant to analyzing the related compositional changes in output.

A. Results on Tests for GNP Separability

Until recently, almost all economists simply assumed that the conditions for GNP separability were valid. In recent years, techniques have been developed which permit the formulating and testing of such an hypothesis.[10]

Evidence on the validity of the GNP separability assumption in producing sectors is mixed. Berndt and Wood [1975a] report results based on annual U.S. manufacturing data, 1947-1971, finding no statistical support for the GNP separability hypothesis. Based on 1954, 1958, 1963, and 1971 data for twelve resource-intensive U.S. manufacturing industries, Morony and Toevs [1975] report rejection of the GNP separability restrictions in six industries; they conclude that in those industries the analysis of value added (GNP), may be complicated with specification error due to the differential impact on capital and labor of changes in natural resources inputs. On the other hand, based on 1963 U.S. interindustry data at the four-digit level, Humphrey and Moroney [1975] were unable to reject the weak separability condition for GNP separability in five of the seven resource-intensive manufacturing industries considered. A similar finding supporting the GNP separability specification has been reported by Griffin and Gregory [1976]; their research was based on pooled cross-section and time-series data for the aggregate manufacturing sector in nine OECD countries, 1955-1969.

In summary, results of empirical tests for the validity of the GNP specification in various producing sectors are mixed and tend to vary considerably by industry. A general, conclusive finding is not yet available.

The GNP separability assumption does not have a simple analog on the consumption side. We note in passing, however, that projections based on either total dependence between energy and GNP or complete independence of energy and GNP both implicitly assume that aggregate energy consumption is unaffected by changes in the <u>distribution</u> of national income. A necessary condition for this to occur is that the consumer's budget share expended on energy must be independent of his income level. This does not appear to be the case, since numerous budget studies indicate that the share of a family's budget spent on energy tends to decline with increases in income level.[11]

To the best of our knowledge, only one study has tested the empirical validity of the utilized capital hypothesis. Berndt and Wood [1975a] find support for the existence of such a composite in U.S. manufacturing, 1947-1971. This result provides support for the notion that the energy-capital composition of utilized capital is independent of all other input prices such as labor or materials, and depends only on the relative prices of capital and energy. On the other hand, as seen in (5) the composite input of utilized capital can be substituted for other inputs -- such as labor.

B. Results on Estimated Substitution Elasticities Between Utilized Capital (Energy-Capital) and Other Non-Capital Inputs

Table I below summarizes results of fourteen studies on possibilities for substitution among energy and non-capital inputs. As shown in the table, most studies find that cross elasticities between energy and labor are positive and significantly different from zero; although energy-labor substitution possibilities are present, they appear to be limited -- certainly less than the large, virtually infinite values implicitly required for the validity of the completely independent energy-GNP forecasting procedure. Similar results appear to hold for energy and other materials.

A second set of cross-elasticity results are those between capital and non-energy inputs. Since those findings are not of principal interest here, we will focus principal attention elsewhere. Briefly, on the basis of numerous studies, it appears that capital and labor as well as capital and other materials are substitutable.

To our knowledge, the only reported empirical results employing utilized capital (the composite of energy and capital) are those of Berndt and Wood

[1975a]. Their empirical analysis, based on annual U.S. manufacturing data, 1947-1971, reports that the cross-price elasticity between utilized capital and labor is about .3; such a result again suggests limited substitutability. The corresponding cross-price elasticity for utilized capital and other materials is about .6.

Finally, some tentative evidence exists, albeit weak, that over the 1947-1971 time period in the U.S. manufacturing sector, technological change was labor-saving but energy-using (see Berndt-Wood [1975b] and Wills [1976]). If true, this result would be especially interesting, since the bias of technological change would have been a form that conserved on the input whose price increased the most (labor) and used most intensively the input whose price increased much less (energy).

C. Results on Substitution Within the Utilized Capital Composite

Compared to evidence on substitution possibilities among energy and non-energy inputs, relatively few results have been published on substitution possibilities between capital and energy within the utilized capital composite. Studies by Berndt-Wood [1975a], Fields-Grebenstein [1977], Fuss [1977], Griffin-Gregory [1976], Hnyilicza [1976], Hudson-Jorgenson [1974], Magnus [1975], Swaim-Friede [1976], and Wills [1976] present apparently conflicting evidence -- some reporting complementarity, others, substitutability. Comparison of the results of these studies is complicated since they differ regarding the inputs considered and the corresponding measure of output. For example Fields-Grebenstein [1977], Griffin-Gregory [1976] and Magnus [1977] consider only K, L, and E, while the other studies consider K, L, E, and M. Thus the corresponding partial elasticity measures hold different variables constant.

TABLE I

Results of Empirical Studies on Substitution Possibilities
Among Energy and Non-Capital Inputs

Study	Data Base	Principal Findings
Berndt-Wood [1975a]	Total U.S. Manufacturing, Annual, 1947-71	Non-zero but limited energy-labor substitutability; slightly more substitutability between energy and other materials.
Christensen-Greene [1976]	Cross-sections of U.S. firms producing power, 1955 and 1970	Labor-fuel substitutability significant in 1955 but substitutability declines substantially to almost zero by 1970; power companies appear to have realized most economies of scale by 1970.
Fields-Grebenstein	U.S. Manufacturing by state, 1971, using two measures of capital: reproducible capital, and total capital (reproducible + working capital).	Significant energy-labor substitutability for both capital specifications.
Fuss [1977]	Canadian total manufacturing, annual by region, 1961-71	Energy-labor substitutability significant; slightly less substitutability between energy and other materials.
Griffin-Gregory [1976]	Nine OECD countries, total manufacturing, 1955, 1960, 1965, & 1969	Non-zero but limited energy-labor substitutability in all nine developed countries.
Hawkins [1975]	Australia, five subclasses of industry groupings, 1959-60	Results suggest energy-labor substitutability; principal focus is on form of adjustment paths.
Hnyilicza [1976]	Two sectors of U.S. economy, annual 1947-71	Slight energy-labor substitutability present in both sectors.
Hudson-Jorgenson [1974]	Nine sectors of U.S. economy, annual, 1947-71	Energy-labor substitutability present over aggregate of nine sectors; other results tend to vary by sector
Humphrey-Moroney [1975]	Seven resource-intensive industries, U.S. interindustry data, 1963	Energy-labor substitutability in 6 of 7 industries

TABLE I

(cont.)

Study	Data Base	Principal Findings
Magnus [1977]	Aggregate Dutch economy, annual, 1950-1974	Non-zero but limited energy-labor substitutability
Moroney-Toevs [1975]	Twelve resource intensive U.S. industries, 1954, 1958, 1963, and 1971	Eight of twelve industries display labor-natural resource substitutability; only one of twelve indicates statistically significant complementarity.
Nordhaus-Tobin [1972]	Aggregate annual U.S. data, 1909-1958	Significant and positive elasticity between value-added (an aggregate of capital and labor) and natural resources (land, and primary energy, and other natural resources).
Swaim-Friede [1976]	Aggregate industrial sector, West Germany, annual, 1954-1966	Limited energy-labor substitutability; more substitutability between energy and non-energy materials.
Tintner-Deutsch-Rieder [1975]	Aggregate annual Austrian data, 1955-72	Energy-labor substitutability (Note: this result due to an assumed Cobb-Douglas functional form).
Wills [1976]	Cross-sections, 1958 and 1963, U.S. Primary Metals industry	Substantial energy-labor substitutability -- but less in 1963 than in 1958.

Differences may also be related to measurement of input quantities and prices. For example, Fields-Grebenstein [1977], using total U.S. manufacturing cross-section data for states in 1971, obtain capital-energy complementarity when using a service price measure for reproducible capital, and capital-energy substitutability when using a value added measure for total capital inputs. These results tend to resolve the apparent differences between the results of Berndt-Wood [1975a], Hudson-Jorgenson [1974], and Griffin-Gregory [1976], as reported in the latter.

All of these studies share certain drawbacks in that none fully takes account of the adjustment process outlined in Section II. Finally, no study computes an elasticity which holds constant the output of utilized capital services and examines only possibilities for substitution between capital and energy.[12]

The lack of firm evidence on energy-capital substitutability is especially disappointing, for in our judgment, it is precisely here where the greatest potential for energy conservation exists. A major contribution of the interdisciplinary resource groups of both the Demand/Conservation and Synthesis Panels is the technical analysis of the substitution possibilities between energy and capital in residential, commercial, industrial, and transportation uses.

IV. IMPLICATIONS FOR CONAES

In the previous pages we have examined two alternative forecasting procedures -- the total dependence method which implicitly assumes zero substitutability among inputs and the substantial independence procedure employed by CONAES which assumes that substitution possibilities between energy and non-energy inputs are significant. The greater the degree of substitution between energy and capital within the utilized capital composite, and the greater the degree of substitution among utilized capital and other inputs, the more appropriate are the CONAES assumptions.

The empirical evidence on substitution possibilities among utilized capital and other inputs (especially labor) suggests that substitutability is present but limited. The extent to which energy demand projections based on these limited substitution possibilities would be consistent with the CONAES projections based on a total independence assumption depends, of course, upon the range in the various CONAES energy demand projections. The greater the range, the more likely that CONAES demand projections and economic growth assumptions will be inconsistent. The magnitude of the potential discrepancy is not known. The Report of the Modeling Resources Group and the work of Hogan and Manne [1977] present a framework in which this discrepancy is interpreted in the context of the value of the price elasticity between value added (K and L) and energy.

Unfortunately, very little reliable historical information is available on possibilities for substitution between capital and energy within the utilized capital composite. This is regrettable, for it is here we believe that substantial potential exists for energy productivity increases. A major contribution of the interdisciplinary economics-engineering-physical science approach of the Demand/Conservation Panel is the delineation of specific examples which illustrate the significant technical substitution possibilities between capital and energy in the residential and industrial markets.

FOOTNOTES

1. For a further discussion of measurement problems in the energy-GNP ratio, see Schipper and Darmstadter [1976].

2. For further discussion, see E.R. Berndt and D.O. Wood [1974].

3. It is more appropriate to speak of the approaches of the CONAES since several separate groups are involved in activities relating to energy demand projection. While the various CONAES groups may differ in their emphasis on particular independent variables, a common feature is a reliance on the independence of energy and GNP. The relevant material for our purposes includes the reports of (i) the Demand/Conservation Panel, (ii) the Supply Panel, (iii) the Synthesis Panel, and (iv) the Modeling Resources Group of the Synthesis Panel.

4. By "nearly perfect" substitution is meant that a small change in the price of one input leads to a substitution of other inputs with almost no change in the level of output in costs. Thus $\partial(\ln X_i)/\partial(\ln P_j) \to \infty$ where X_i is input quantity and P_j is the price of the j-th factor.

5. The homogeneity assumption is used only to facilitate exposition. An example of a study involving non-homothetic functions is Fuss [1977].

6. In the present context (equation 1), K and L are said to be weakly separable from the other inputs E and M if and only if

$$\partial\left[\frac{\partial Y}{\partial K}\Big/\frac{\partial Y}{\partial L}\right]/\partial X = 0, \quad X = E, M$$

For further discussion, see Berndt and Christensen [1973].

7. See E.R. Berndt and L.R. Christensen [1973] for a more complete and rigorous discussion of these conditions.

8. The reader will note that the relevant references are for the past two years. Almost certainly we are not aware of all current research in this area. Thus, although we have tried to present an exhaustive survey, we inadvertently may have omitted some studies.

9. For further discussion, see J. Daniel Khazzoom, "Background," in J. Daniel Khazzoom, editor [1976], pp. I-3 to I-27.

10. It should be noted that some problems still remain; see, for example, Blackorby, Primont, and Russell [1977].

11. In economic jargon, budget shares for a good are independent of income only if the income elasticity is unitary; the results of budget studies suggest, however, that the income elasticity of demand for energy is less than unity. A related empirical result based on time-series data has been reported by Jorgenson [1974]; see also the recent study by Pindyck [1976] and the survey by Taylor [1976].

12. The analysis in Section II suggests a measure of energy conservation or energy productivity, namely, the percent change in the composition of energy and capital for a given flow of "utilized capital." For further discussion of measures of energy conservation see Schipper and Darmstadter [1977].

13. Even when assumptions are the same between studies, there may be significant differences in terms of the point where prices and quantities are measured. For example, is energy input valued at point of production or as delivered? These measurement issues greatly complicate the exact comparison of empirical elasticity estimates. For a discussion and illustration of this point, see the Report of the Modeling Resources Group, CONAES Synthesis Panel.

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