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Substitution between activities with different energy intensities*

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An increase in the real price of energy will have both direct and indirect effects on the composition of activities with different energy intensities. Of the two effects, the direct one is the most intuitive. It is usually presumed to reduce participation in energy-intensive activities, e.g., reducing vehicle miles driven. We show that the direction of the (income-compensated) substitution effect is not known unambiguously but instead depends upon the energy intensities of the activities as well as the utility function. Then focusing upon the two-activity case, we show that (1) greater input substitution within each activity decreases this shift between activities, and (2) value-added measures of output are likely to bias the true substitution between activities. Under some conditions, an increase in the energy price can actually result in an apparent shift towards the more energy-intensive activity when measured in terms of value added.

1. Introduction

The reduction in the energy–output ratio in many developed market economies since 1973 has been remarkable. In the United States, for example, energy use remained virtually level from 1973 to 1985, while economic activity (GNP) increased some 30 percent. It is widely recognized that declining energy intensity has taken many forms. Substitution away from energy occurs not only in individual processes or pieces of equipment but also among sectors, industries, and goods and services. For example, recent estimates of the decline in energy consumption in manufacturing suggest that at least one-third of the reduction in energy intensity between 1974–1981 can be attributed to shifts among individual industries.[1] This is a conservative estimate because even greater effects can be found when

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[1] Past studies have been reviewed in Boyd et al. (1986) and Huntington and Myers (1986). These studies include those by Faruqui et al. (1986), Fujime (1985), Jenne and Cattell (1983), Marlay (1983, 1984, 1986), Myers and Nakamura (1978), Roop and Belzer (1986), Samuels et al. (1984), and Werbos (1984, 1986). See also Doblin (1988).

feedstocks are included or for periods encompassing more recent years since 1981.[2]

Economists generally anticipated significant reductions in energy use per dollar of output due to higher energy prices, and in hindsight, their optimism about the importance of energy prices appears justified. In addition to their effects on input choice within an industry or activity, energy price increases can have two distinct effects on the composition of goods and services by (1) directly making energy-intensive activities more expensive relative to others, and (2) indirectly shifting the composition of demand through changes in aggregate and factor income. Indirect effects could arise because energy shocks redistribute income between different factor owners [Solow (1987)] or because they reduce investment and the demand for capital goods [Hudson and Jorgenson (1978) and Jorgenson (1982)].

Of the two mechanisms affecting the composition of economic activity, the direct effect is the most intuitive. Moreover, the direction of the response is seldom questioned; households always reduce their participation in the energy-intensive activity. Indirect effects, on the other hand, could favor either set of goods [Solow (1987)].

Economists frequently postulate that households will reduce vehicle miles driven in response to higher gasoline prices or opt for less comfort as heating fuel costs escalate. At the economy-wide level, it is tempting to link the decline in certain energy-intensive industries to higher energy prices. And yet, on what basis are these predictions made? Do they emanate from the rigors of economic theory or are they a product of more informal arguments appealing to one's intuition?

We ask initially what light can be cast on the direct role of energy prices in determining the composition of activities by considering in the next section the basic model of the consumer's choice between activities with different energy intensities. We show in section 2 that conclusive results cannot be derived for the change in a particular activity, unless further restrictions are imposed on the utility function or the energy intensities of the activities. In section 3, we impose one such restriction, the simple two-activity case, which provides a very tractable framework for examining how input substitution within an activity shapes the direct effect of energy price changes on that activity. In section 4, we provide some numerical examples of the direct effect of energy price changes on the composition of manufacturing activity and show that the direct effect is not necessarily relegated to a minor role by energy's small share of total production costs. The biases introduced by using a value-added rather than gross output measure of

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[2] Due to data constraints for industrial energy demand, most studies analyze the trends through 1981. Exceptions are Marlay (1986) and Werbos (1986). The latter extends coverage to include feedstocks, the primary energy content of electricity, and the agriculture, construction, and mining sectors.

economic activity are also considered here. Conclusions and implications of the analysis are discussed in section 5.

2. Substitution effects

Consider a decisionmaker who engages in a set of activities employing both energy units and other goods, subject to a typical budget constraint.[3] He maximizes the following function:

$$\phi = U(Z_1,\dots,Z_n) + \lambda\left(Y - \sum_{i=1}^{n} X_i - p\sum_{i=1}^{n} E_i\right) \quad \text{for} \quad i=1,\dots,n, \tag{1}$$

where Z_i denotes an activity, X_i the units of non-energy goods used in activity i, E_i the units of energy used in activity i, Y income, and p the price of energy relative to that of non-energy good, the numeraire.

To emphasize the substitution among activities rather than between inputs in the production of an activity, we employ fixed-coefficient production functions:

$$X_i = x_i Z_i \quad \text{and} \quad E_i = e_i Z_i, \tag{2}$$

where x and e are the input coefficients in activity i for non-energy and energy inputs, respectively. Even in this limited case, we show that conclusions about the direction and extent of substitution among activities with different energy intensities are not warranted. These concerns are even more germane to the less limiting case allowing substitution between inputs, particularly where energy price changes cause factor reversibility, i.e., the more energy-intensive activities switch places with the less energy-intensive ones.

The first-order conditions are:

$$U_i - \lambda\pi_i = 0, \quad \text{and} \quad Y - \lambda\sum_{i=1}^{n}\pi_i Z_i = 0, \quad \text{for} \quad i=1,\dots,n. \tag{3}$$

where

$$\pi_i = x_i + p e_i,$$

Comparative statics follow from the total differentiation of (3), yielding

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[3] This model of energy demand has been widely used and is based upon Lancaster's (1966) more general model of consumers combining characteristics of goods to produce service flows. The restrictions noted in this section were developed by DeSerpa and Huntington (1978) with respect to another application, Becker's (1965) theory of time.

$$\begin{bmatrix} U_{11} & U_{12} & \dots & U_{1n} & -\pi_1 \\ U_{21} & U_{22} & \dots & U_{2n} & -\pi_2 \\ \vdots & \vdots & & \vdots & \vdots \\ U_{n1} & U_{n2} & \dots & U_{nn} & -\pi_n \\ -\pi_1 & -\pi_2 & \dots & -\pi_n & 0 \end{bmatrix} \begin{bmatrix} \mathrm{d}Z_1 \\ \mathrm{d}Z_2 \\ \vdots \\ \mathrm{d}Z_n \\ \mathrm{d}\lambda \end{bmatrix} = \begin{bmatrix} F_1 \\ F_2 \\ \vdots \\ F_n \\ G \end{bmatrix}, \tag{4}$$

where

$$F_i = \lambda(\mathrm{d}x_i + p\,\mathrm{d}e_i + e_i\,\mathrm{d}p),$$

and

$$G = -\mathrm{d}Y + \sum_{i=1}^{n} Z_i(\mathrm{d}x_i + p\,\mathrm{d}e_i + e_i\,\mathrm{d}p) \quad \text{for} \quad i = 1, \dots, n.$$

Eq. (4) relates changes in activity levels to changes in energy (non-energy) intensities $e_i(x_i)$ and changes in the relative price of energy p.

We focus on the substitution effects because the income effects will clearly depend upon the utility function. It is helpful to consider initially an exogenous change in the energy intensity of the first activity, due perhaps to an improvement in the energy efficiency of the equipment used in that activity that is unrelated to shifts in the relative price of energy. Define D as the bordered Hessian determinant and D_{ij} as the cofactor of the element in row i and column j. The income-compensated substitution effect for the first activity can then be expressed as

$$S_{1e} = \lambda p D_{11}/D < 0, \tag{5}$$

because D_{11} is a principal minor of D. A technical improvement in energy efficiency will encourage greater levels of the activity because it lowers that activity's effective price, π_1. The income effect will operate in concert with this substitution effect if the activity is a normal good.

The substitution effect for a change in the relative energy price is fundamentally different from the previous result. This effect for the first activity can be written as

$$S_{1p} = \lambda \sum_{i=1}^{n} e_i D_{i1}/D, \tag{6}$$

the sign of which cannot be determined because D_{21} and all succeeding terms are not principal minors of D. Moreover, the income effect can operate in either direction, further obfuscating the direction of the change in activity levels.

We can, however, derive a substitution effect of known direction under certain conditions. First, from the alien cofactor theorem,

$$\pi_n D_{n1} = -\sum_{j=1}^{n-1} \pi_j D_{j1} \quad \text{for} \quad j \neq n.$$

Next, define $\theta_i \equiv pe_i/\pi_i$, the energy cost share for activity i. Substituting these two expressions into (6) yields

$$S_{1p} = \frac{\lambda}{pD}\left[(\theta_1 - \theta_n)\pi_1 D_{11} + \sum_{j=2}^{n-1} (\theta_j - \theta_n)\pi_j D_{j1}\right]. \tag{7}$$

The first right-hand term in (7) will be negative if $\theta_1 - \theta_n > 0$ because $D_{11}/D < 0$. Note that the substitution effect is unambiguously determined in the two-activity case because there are no succeeding terms under these conditions. As long as $\theta_1 > \theta_n$, $S_{1p} < 0$. An increase in the relative energy price will induce substitution away from the energy-intensive activity.

When there are three or more activities, the other terms in (7) could diminish or even reverse this negative effect. The substitution effect for the first activity will remain negative if

$$-(\theta_1 - \theta_n)\pi_1 D_{11} > \sum_{j=2}^{n-1} (\theta_j - \theta_n)\pi_j D_{j1}.$$

Thus, the sign of the substitution effect will depend upon the utility function (as incorporated by the D_{ji} terms) as well as upon the relative energy intensities (θ) of all the activities. Whether activities are complements or substitutes in consumption could influence the direction as well as magnitude of this response.

If all activities are substitutes in consumption (i.e., $D_{ij} > 0$ for all $i \neq j$), an increase in the energy price will induce an unambiguous substitution effect away from the most energy-intensive activity and towards the least energy-intensive activity. Suppose that activity 1 has the highest energy cost share, i.e., is the most energy-intensive. Then, define the nth activity to have the second highest energy cost share, so that $\theta_1 > \theta_n > \theta_j$ for $j = 2, \ldots, n-1$. Now the first term as well as all succeeding terms in (7) are negative for an energy price increase because $\theta_j - \theta_n < 0$ and $D_{ij} > 0$. By analogous reasoning and defining the nth activity to have the second lowest energy cost share, all terms in (7) will be positive for the least energy-intensive activity because $\theta_1 < \theta_n < \theta_j$ for $j = 2, \ldots, n-1$. The direction of the substitution effects for all other activities, however, are indeterminable unless the above restriction is imposed.

A higher relative energy price will induce substitution effects that generally move the decisionmaker away from activities that use more energy; rational decisionmakers will reduce the level of total energy used. However, that reduction can be accomplished through many avenues. With n goods using different combinations of E and X, energy use can be reduced by substituting between any set of two activities. If $\theta_1 > \theta_2 > \theta_3$, e.g., energy can be reduced by replacing the first activity with either the second or third, or by replacing the second activity with the third one. This point can be seen directly from (7) above. In general, one cannot determine a priori whether participation in a particular activity will be discouraged by a higher relative price of energy from knowledge of energy intensities alone. The decisionmaker's utility function also matters. Additional complications could arise if one introduces energy–goods substitution within an activity. If factor reversals are not ruled out, activities that are relatively more energy-intensive could become relatively less energy-intensive and vice versa.

3. Direct substitution effects with two activities

Some useful insights about the broad issue of substitution away from energy-intensive activities can be developed in the two-activity case. In this section, we allow energy and goods to be substituted for each other within an activity.

As in the previous section, activities (Z) are produced by combining energy (E) and non-energy (X) inputs. Substitution between inputs in each activity is governed by a production function with constant returns to scale:

$$Z_i = Z_i(E_i . X_i). \tag{8}$$

It is convenient to consider percent deviations from a set of predetermined baseline conditions, denoting them by small letters, i.e., $z_i = \partial \ln Z_i$ represents the percent deviation (expressed as a decimal) in the output in the first activity. The production functions can then be written as

$$z_i = \theta_i e_i + (1 - \theta_i) x_i, \tag{9}$$

where θ_i represents the cost share of energy in activity i as in the previous section. From Euler's theorem, the dual of (9) can be written

$$p_i = \theta_i p_e + (1 - \theta_i) p_x . \tag{10}$$

The consumption of each activity is determined by the decisionmaker's utility function:

$$U=U(Z_1,Z_2). \tag{11}$$

If the function U is assumed to be constant elasticity of substitution (CES), the deviation in the ratio between the quantities consumed of goods 1 and 2, after substituting (10), becomes

$$z_1-z_2=-\eta(p_1-p_2)=-\eta(\theta_1-\theta_2)(p_e-p_x), \tag{12}$$

where η denotes the elasticity of substitution between products in consumption. As in (7), the direction of the effect on relative output in the two sectors will depend upon which good is relatively more energy intensive. If $\theta_1>\theta_2$, consumption will shift away from Z_1, the energy-intensive activity. In this case, however, the cost share of energy in an activity can change as the relative prices of energy and goods change.

This result can be shown most tractably by adopting the convenient CES function for production as well:[4]

$$Z_i=[a_iE_i^{-\rho_i}+(1-a_i)X_i^{-\rho_i}]^{-1/\rho_i}, \tag{13}$$

where a is a distribution parameter, ρ is a substitution parameter related to the elasticity of substitution σ by $\rho=(1-\sigma)/\sigma$, and the subscript i denotes the sector.

When purchasing inputs under competitive conditions, decisionmakers will set the marginal product of each input equal to its price, resulting in the following conditional input demand relationships:

$$x_i=z_i-\sigma_i(p_x-p_i), \tag{14a}$$

and

$$e_i=z_i-\sigma_i(p_e-p_i). \tag{14b}$$

Changes in the relative input cost shares, $\gamma_i=P_eE_i/P_xX_i$, can be represented by combining eqs. (14a) and (14b) and rearranging terms:

$$\partial\ln\gamma_i=(1-\sigma_i)(p_e-p_x). \tag{15}$$

Energy's cost share can be calculated by noting that $\theta_i=\gamma_i/(1+\gamma_i)$. Thus, for

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[4] Hogan and Manne (1977) and Sweeney (1979) have used CES functions to discuss the importance of substitution between energy and non-energy inputs for aggregate energy–economy interactions. The CES function is less appropriate for empirical studies when there are two or more non-energy inputs (labor and capital) that cannot be separated from energy. For these purposes, researchers [e.g., Berndt and Wood (1975), Hudson and Jorgenson (1974)] often use flexible forms such as the translogarithmic production function.

a non-incremental increase (decrease) in the energy price, the energy cost share of an activity will increase (decrease) if the elasticity of input substitution for that activity is below unity. These shifts in cost shares for both activities will change the response of the sectoral mix to energy price changes represented by (12).

Hence, the direct effects of an energy price increase (holding the price of other goods constant) on the consumption of activities need not be small simply because energy has historically represented a small proportion of total production costs in many activities. The energy cost share for the energy-intensive activity could rise substantially if input substitution in that activity were rather limited. The energy cost share for the other activity could remain unchanged or even decline if input substitution were considerably greater in that activity. Under these conditions, the shift away from the energy-intensive activity could be substantially stronger than would be implied from a simple comparison of historical energy cost shares.[5]

4. Compositional shifts in industrial activity

A significant part of the reduction in energy intensity of manufacturing has occurred because output has shifted from the energy-intensive sectors producing basic materials for other industries to the rest of manufacturing. While it is tempting to argue that energy prices have directly contributed very little to this shift because energy costs shares are relatively low, the preceding discussion suggests that substitution between inputs is also critical in shaping this response. In this section, we demonstrate how different assumptions about the substitution opportunities within the two sectors can change the magnitude of the direct effect.

In moving to a more aggregated level (manufacturing or the economy), we make several simplifying assumptions. Both product and factor markets operate competitively. The consumption of each activity is determined by a community utility function, or alternatively by the summation of identical individual utility functions for consumers owning equal units of energy and non-energy inputs. For parallelism with the preceding sections, we aggregate all non-energy inputs into one factor. And finally, we focus on the change in the relative price of energy and the non-energy inputs, i.e., we change the energy price while holding the price of non-energy inputs constant.

Table 1 summarizes the major shift within manufacturing away from energy-intensive activities during the 1974–1981 period.[6] The materials-

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[5] This result is analogous to Hogan and Manne's (1977) conclusion that the reduction in an economy's aggregate output due to large energy price changes can be substantial if input substitution in production is limited on an economy-wide basis.

[6] By focusing on this period, we exclude the effect of the strong U.S. dollar in the early eighties.

Table 1

Energy intensities within U.S. manufacturing, 1974–1981.[a]

	1974	1981
All manufacturing		
Energy	12,845.2	11,145.5
Output	815.9	934.6
Energy–output ratio	15.7	11.9
Energy cost share	2.4%	4.1%
Materials		
Energy	9,335.0	7,883.6
Output	213.5	220.3
Energy–output ratio	43.7	35.8
Energy cost share	6.6%	12.4%
Pct of total output	26.2%	23.6%
Other manufacturing		
Energy	3,510.2	3,261.8
Output	602.4	714.4
Energy–output ratio	5.83	4.57
Energy cost share	0.9%	1.6%
Pct of total output	73.8%	76.4%

[a] Energy (TBtus) from Census of Manufacturers. Gross Output (1982 $B) from Wharton EFA data base. Materials industries include paper, chemicals, petroleum, stone-clay-glass, and primary metals. Energy cost shares based upon energy price of $1.50 per million Btu in 1974 and $3.45 per million Btu in 1981.

producing sector is comprised of five major industries producing basic materials for other sectors of the economy: paper and pulp products; chemicals; petroleum refining; stone, clay, and glass; and primary metals.[7] While energy intensity in physical units declined in both sectors, the reduction for aggregate manufacturing was greater than that within either sector because output was shifting away from the materials-producing sector.

Fig. 1 emphasizes how different assumptions about the input substitution between inputs can influence the direct impact of energy price changes on the shift between these two sectors.[8] Each of the six curves shows this relationship under a different assumption for the elasticity of substitution between inputs within the energy-intensive, materials-producing sector, σ_1. Based upon the Energy Modeling Forum (1980), a range of elasticities of substitution below unity have been considered.[9] Greater substitution occurs

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[7] Myers and Nakamura (1978) use a two-sector disaggregation to demonstrate the importance of a shift between sectors on energy use. Boyd et al. (1987) estimate that a two-sector split of manufacturing can account for 80 percent of the decline in fossil fuel intensity attributable to shifts among sectors between 1974 and 1981.

[8] These simulations are based upon (12) and (15).

[9] The EMF study found an elasticity of substitution ranging from 0.3 to 0.7 for most energy models. Since these elasticities are measured at the secondary (wholesale) level responses at the retail level could be substantially higher.

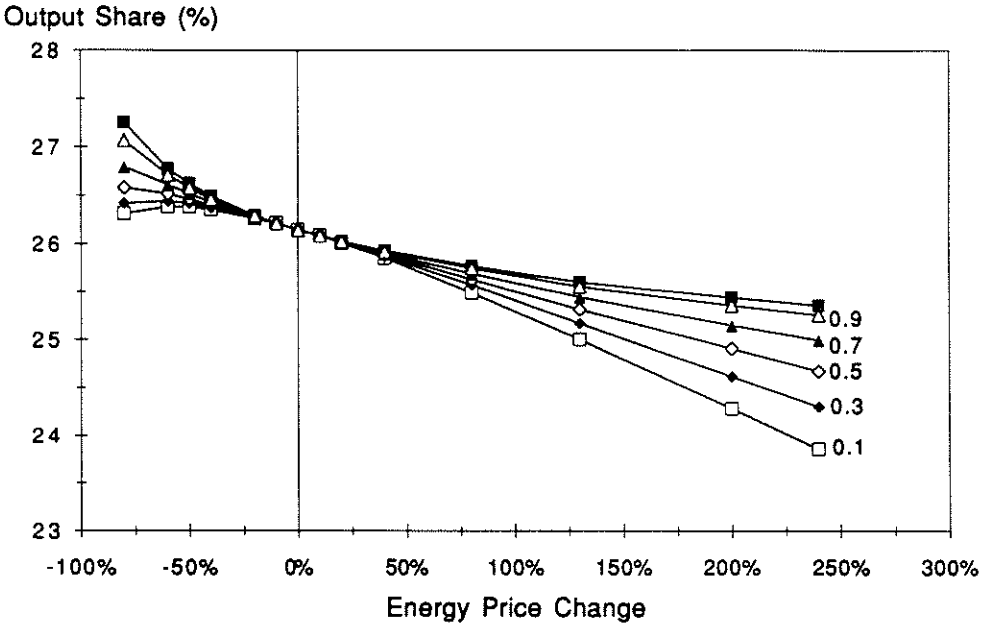

Fig. 1. Effect of energy price change on energy-intensive sector's share of manufacturing output.

with higher σ_1. An increase in the energy price (horizontal axis) reduces the share of industrial output attributable to the energy-intensive sector (vertical axis), while a decrease in the energy price increases it. These curves have been constructed by holding σ_2, the elasticity for the other sector, equal to 0.9 and η, the elasticity of substitution in consumption between the two products, equal to 0.6.

Less substitution between inputs raises the impact of an energy price increase on the output share of the energy-intensive sector, but decreases the effect of an energy price reduction. This asymmetry results from the fact that when $\sigma_1 < 1$, energy's cost share in this sector [and hence the coefficient in (12)] is increasing when the energy price rises but decreasing when it falls. The Cobb–Douglas result embodying constant cost shares for energy (denoted by black squares) represents a lower-bound estimate for the effect of an energy price increase, given the range of elasticities considered (all below unity), but an upper-bound estimate for the effect of an energy price decrease. For the 130 percent increase in real energy prices during this period, the energy-intensive sector's share of output would fall from 26.3 to 25.2 percent with constant energy cost shares, but would fall to 24.1 percent if σ_1 were restricted to 0.1. Thus, the direct effects of energy price changes could be explaining much of the observed decline in this sector's relative importance from 26.2 to 23.6 percent during this period.[10]

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[10] The energy cost shares in table 1 increase substantially in each sector, implying a relatively low substitution away from energy within each sector, ranging from 0.2 to 0.3 for the 130 percent increase in real energy prices during this period. These responses, however, are not long-run elasticities but a mixture of short- and mid-term responses.

These results are not very sensitive to changes in the substitution between inputs within the other manufacturing sector. Reducing σ_2 from 0.9 to 0.1 changes the share of the energy-intensive sector by at most 0.2 percentage points for a 250 percent increase in the energy price. The energy intensity of the materials-producing sector dwarfs that of the other sector. As a result, changes in the cost share of the other sector have a relatively minimal effect on the shift in gross output between sectors.

It is important to note that activity levels in table 1 and fig. 1 are being measured in gross output rather than value-added (GNP) terms. Empirical researchers often favor the gross output measure because tests have often indicated that energy and non-energy inputs are not separable. Our two-input analysis suggests another reason for preferring gross output when analyzing the phenomenon of compositional shift within industry. If industrial activity is measured in terms of value added (e.g., real GNP), robust conclusions about the direction of substitution between sectors are not possible, even in the two-sector case.

This conclusion can be shown by noting that with two inputs, output in value-added terms is gross output minus energy payments, or X_i. The effect of a shift in the relative input prices on activity i's value added can be derived by substituting (10) into (14a):

$$x_i = z_i + \sigma_i \theta_i (p_e - p_x). \tag{16}$$

Using (12) and (16), the ratio of the value added in the two sectors, X_1/X_2, will change according to

$$x_1 - x_2 = -[(\eta - \sigma_1)\theta_1 - (\eta - \sigma_2)\theta_2](p_e - p_x). \tag{17}$$

The direction of the shift no longer depends exclusively on the relative energy intensities of the two activities. It will now depend upon the elasticities of substitution in consumption as well as in each sector's production. For an increase in the relative price of energy,

$$x_1 - x_2 < 0 \quad \text{if} \quad \theta_1 > [(\eta - \sigma_2)/(\eta - \sigma_1)]\theta_2. \tag{18}$$

For small changes in the relative energy price, (17) shows that more input substitution in the energy-intensive activity (Z_1), ceteris paribus, increases the tendency of a shift *towards* that activity, when it is measured in value-added terms. Greater input substitution in the other activity does the opposite.

The bias introduced by measuring value added instead of gross output can also be examined. Subtracting (17) from (12) yields

$$(z_1-z_2)-(x_1-x_2)=[\sigma_2\theta_2-\sigma_1\theta_1](p_e-p_x), \tag{19}$$

implying that for an incremental increase in the relative energy price,

$$(z_1-z_2)>(x_1-x_2) \quad \text{if} \quad \theta_2/\theta_1>\sigma_1/\sigma_2. \tag{20}$$

Value added will be an unbiased measure of the shift in gross output only when the ratio of the energy intensities of the two activities equals the inverse of the ratio of the two substitution elasticities in production. Otherwise, it will be a biased measure, with the direction and magnitude of this bias dependent upon the relative energy cost shares and input substitution elasticities of the two activities.

5. Conclusion

While higher energy prices have induced market economies to save energy in a variety of ways, their effect on the level and mix of individual activities or industries must generally remain ambiguous from a strictly theoretical perspective. Knowledge of the energy intensities of different sectors or activities is insufficient for determining the direction of substitution effects of higher energy prices on activities with different energy intensities, unless additional restrictions are placed upon the utility function or the relative energy intensities. This ambiguity arises because an energy price change shifts the effective prices of all activities, while the direction of a substitution effect is determinable only when the activity's own price changes, holding all other activity prices constant. While it may be intuitively appealing to suggest that the participation in more energy-intensive activities will be affected more because their effective prices will change more, the outcome will depend partially upon the decisionmaker's utility function as well.

These results suggest caution in linking changes in the composition of economic activity directly to energy price changes. In the face of a general energy price increase, households will have incentives to curtail some energy-intensive activities. They may, for example, reduce the number of miles driven in their automobiles. However, they may also save energy in other ways. They can reduce the energy intensity of other activities or participate less in other activities that use significant energy inputs. Predictions that households will always reduce the number of miles driven in response to a general increase in energy prices may have some empirical content,[11] but households that refrain from such behavior are not necessarily behaving irrationally. For similar reasons, one must be careful in ascribing the post-embargo decline in the share of specific energy-intensive sectors, such as certain materials-producing industries, directly to the higher energy prices.

Higher energy prices will generally shift activity away from energy-intensive sectors, even though the effect on specific industries cannot be predicted a priori. Our two-sector analysis has been useful in establishing that the direct effects of energy price shocks on the composition of goods and services will not necessarily be small just because historical cost shares for energy in each sector are small. The energy cost share in an activity will rise when the elasticity of substitution between energy and other inputs is less than one. This effect can lead to relatively large shifts away from the energy-intensive sector due to large, non-incremental price increases under these conditions. Moreover, there will be an asymmetry in the response of the output mix to energy price changes because energy cost shares decrease with a reduction in the energy price when input substitution is limited.

In addition, conclusions about the effect of energy prices on the composition of economic activity in value-added terms are ambiguous, even in the simple two-sector model. An increase in the price of energy relative to other inputs can induce a direct substitution effect towards the energy-intensive sector, if input substitution in this sector is very large relative to the other sector. More generally, value-added measures of output will tend to misrepresent the actual shift in gross output away from the energy-intensive sector, with the direction and extent of the bias dependent upon the relative energy costs shares and potentials for input substitution in the two activities.

These considerations suggest that measures of the substitution between activities or industries will be sensitive to the methodology used. While input–output models are useful for decomposing the indirect effects of an energy price shock on the composition of economic activity, they will tend to exaggerate the substitution effect under the standard assumption of fixed technological coefficients. While these models are increasingly being expanded to incorporate variable coefficients, our analysis shows the importance of implementing such extensions with care so that accurate input substitution responses are used in the model. Similar caveats apply to general equilibrium, interindustry models, e.g., see Hudson and Jorgenson (1974). Finally, many economic models project a value-added measure of sectoral output to be consistent with gross national product as reported in the national income accounts, thus ignoring the role of intermediate products

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[11] Most empirical models of gasoline demand embrace this assumption. See the survey by Dahl (1986). Note, however, that vehicle miles are closely tied to the state of the economy and that observed declines in driving could reflect the economic recession resulting from higher energy prices.

like energy. The substitution effect of energy price changes on the composition of output derived from such models, however, are likely to be biased estimates of the shift in gross output terms.

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