Dynamic Factor Demands and Energy Substitution in Regional U.S. Manufacturing

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Although energy substitution in U.S. manufacturing has been studied in great depth at the national level, little attention has been paid to the regional level. However, regions may differ in their use of energy for a variety of reasons. The main objective of this study is to estimate region-specific demands for energy using a dynamic model for two-digit SIC Code manufacturing sectors. We derive own and cross-price elasticities for energy for different regions and we compare them. We, thus, provide information which has implications for a region specific energy policy.

Introduction

Many economic studies have been conducted in recent years in response to problems created by increasing energy prices during the 1970's. Manufacturing has received special interest with the analytical focus being on the substitution patterns of energy with other inputs-capital, labor and materials. Berndt and Wood, Griffin and Gregory, Pindyck, Fuss, and Halvorsen, among others, have made significant contributions to the energy-substitution literature. However, for the most part these studies have been conducted at the aggregate level, mainly concentrating at total U.S. manufacturing and sometimes at U.S. manufacturing sectors disaggregated at the two-digit SIC level. To date little attention has been given to energy substitution relationships at the regional level in the U.S. Nevertheless we might expect regions to differ in the way they use energy in production on the grounds of differences in the endowment of resources, in industrial mixes, and in institutional arrangements.

Interregional differences in production structures have been the concern of many analyses over the years. Important contributions to the study of regional production differences were the works of Vinod, Lande and Gordon, and Moroney who estimated aggregate U.S. production functions and used the results to calculate production characteristics at state or census region points. Gallaway and Alperovich took a different path and applied separate production functions for each region. Gallaway used a capital-labor Cobb-Douglas specification and found that differences in production structures between the Middle Atlantic States and the South Atlantic States were not statistically significant and could not explain wage differentials between these two regions. Alperovich estimated a two-input CES production function for various two-digit manufacturing sectors in nine census regions. Capital-labor substitutability was found to vary across the regions. However, this variation was not statistically significant, with the exception of a few sectors, thus implying that regional production functions are similar.

None of the above regional analyses have included energy as an input. Among the few studies that explicitly address energy are the works of MacAvoy and Pindyck, and Walton. MacAvoy and Pindyck found clear differences among regions in demand elasticities of natural gas. Walton studied energy substitutability for four manufacturing sectors in the Middle Atlantic region. She found substitutability between capital and energy (counter to the aggregate results of Berndt and Wood), substitutability between labor and electricity while the evidence for labor and fossil fuels was divided.

The main objective of this study is to esti-

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mate *region-specific* input demands for capital, labor, energy and materials for manufacturing sectors. In this respect, although we share a lot with the research reported recently by Harper and Field,[1] we depart from them and from others in that for the first time a dynamic approach is being used to study regional input demands and energy substitution in particular.

Dynamic disequilibrium models have recently developed along the basic assumption that adjustments of certain "quasi-fixed" inputs are incorporated into the production process of firms so that it becomes an endogenous part of their total optimizing problem. At any particular point in time, therefore, firms may be out of long-run equilibrium. Research with dynamic models of this type to investigate energy use has been carried out by Berndt, Fuss and Waverman (1980), Denny, Fuss and Waverman, and Berndt and Morrison. The present study utilizes such a dynamic model to investigate energy use in regionally disaggregated two-digit manufacturing sectors in 1971–73.[2] This analysis gives insights in the directions of energy price impacts at the regional level and in the adjustment process during the 1970's.

In the next section we discuss the model and data used. Then we present our results. In the final section we summarize our conclusions and the policy implications of our findings.

Model and Data

The theoretical foundations of the dynamic model used in this study can be found in the works of Lucas (1967a, 1967b), Lau, McFadden, Treadway, and Berndt, Fuss and Waverman (1977).

Define the production function of the firm as:

$$(1) \qquad Y(t) = F\,[Y(t), x(t), \dot{x}(t), t]$$

where Y(t) is output, v(t) and x(t) are, respectively, the vectors of variable and quasi-fixed inputs, $\dot{x}(t)$ is the rate of change of the quasi-fixed inputs and t is an index of technology. Costs of adjustment are represented within this production function as $\partial Y(t)/\partial \dot{x}(t) < 0$, i.e., as output foregone due to inputs being devoted to changing the stock of quasi-fixed inputs.

In the short-run firms can be viewed as minimizing normalized variable costs $C = \Sigma_j^M P_j V_j$ conditional on P_j, Y, x_i and $\dot{x}_i$, where variable input prices have been normalized, i.e., $P_j = \hat{P}_j/\hat{P}_1$.

The normalized restricted cost function (NRCF)

$$(2) \qquad C = C\,(P, x, \dot{x}, Y, t)$$

under standard regularity conditions on F is increasing and concave in P, increasing and convex in $\dot{x}$, and decreasing and convex in x. Moreover, the partial derivative of the NRCF with respect to the normalized price of any variable input P_j equals the short-run cost-minimizing demand for v_j

$$(3) \qquad \frac{\partial C}{\partial P_j} = V_j \qquad \text{for } j = 2, \ldots., M$$

while the partial derivative of C with respect to the quantity of any quasi-fixed input equals the negative of the normalized shadow service price of the quasi-fixed input

$$(4) \qquad \frac{\partial C}{\partial x_i} = -\,u_i \qquad \text{for } i = 1, \ldots., N$$

where $u_i = q_i\,(r + \mu_i)$ and q_i is the normalized (by $\hat{P}_1$) asset purchase price of the ith quasi-fixed factor, r is the rate of return and μ_i is the rate of depreciation. The dynamic optimization problem facing the firms is to minimize the present value of the stream of future costs:

$$(5) \qquad L(o) = \int_0^\infty e^{-rt} \left(\sum_{j=1}^{M} \hat{P}_j\, v_j + \sum_{i=1}^{N} \hat{q}_i\, I_i \right) dt$$

where $I = \dot{x} + \mu_i x_i$ is the gross addition to the stock of the ith quasi-fixed factor. This minimization is accomplished by choosing the time paths of the control variables v(t), $\dot{x}(t)$ and the state variable x(t) that minimize L(o), given initial conditions x(o) and v(t), x(t) > 0.

Since the NRCF gives the optimal demand for the variable factors conditional on the values of the quasi-fixed inputs, we can substi-

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[1] This research along with that reported by Harper and Field was supported by the National Science Foundation, Grant No. SE5 - 802 - 0585.

[2] The use of time-series, cross-sectional data has been considered as an interesting extension of the dynamic models for future research (see, for example, Berndt, Fuss and Waverman (1980)). To the best of our knowledge this is the first time that such an extension is implemented. We should also mention that we believe that the three-year data when combined with cross-sectional observations gives enough variability for the variables so that a long-run equilibrium can be described in a dynamic analysis.

tute (2) into (5), and integrate the resulting function by parts to obtain:

$$(6)\quad L(o) + \sum_i^N q_i x_i(o) = \int_0^\infty e^{-rt}\left\{C(x,\dot{x},P,Y,t) + \sum_i^N u_i x_i\right\} dt$$

Minimizing (6) is equivalent to minimizing (5) since the term $\Sigma_i\, q_i x_i(o)$ indicates an initial condition and is not an element of the optimal path. This problem has been related to the flexible accelerator or partial adjustment models by Treadway to obtain solution for $\dot{x}$ (see Appendix A). Our model was specified in terms of labor (L), energy (E), materials (M), and one quasi-fixed input, capital (K). In this case of one-quasi-fixed input $\dot{x}_1$ can be generated as an approximate solution to:

$$(7)\quad \dot{x}_1 = M^*_1\,(x^*_1 - x_1)$$

where

$$(8)\quad M^*_1 = -\tfrac{1}{2}\left[r - \sqrt{r^2 - \frac{4C^*_{x_1x_1} + r\,C^*_{\dot{x}_1\dot{x}_1}}{C^*_{\dot{x}_1\dot{x}_1}}}\right]$$

while x_1 and $\dot{x}_1$ subscripts denote derivatives, and the star means that the relevant functions are evaluated at the point x^*_1 and $\dot{x}_1 = o$. We should note that the stationarity assumption, i.e. $\dot{x}_1 = o$, imposes the restriction of a fixed optimal technology indicated by x^*_1 (see Karp and Shumway). In our case this seems reasonable as the time span is short.

To derive our econometric model we specify a quadratic functional form to approximate the NRCF(2). We further assume that:

i. prices are given to the firms and that static expectations prevail about them,
ii. continuous changes of capital K may be represented by discrete changes, $K_t - K_{t-1} = \Delta K$,
iii. production in t is a function of the capital stock of the previous period, K_{t-1}. This means that any capital cost adjustment during the period affects production through the cost of adjustment, only.

Before we incorporate these assumptions into our model, let us briefly discuss their strengths and limitations. The presentation of NRCF by a quadratic form is a convenient assumption that leads to a multivariate linear differential equation system, the solution of which can be approximated by the flexible accelerator adjustment mechanism. However, we should mention here that Epstein described a procedure that can generate a large class of practical functional forms for dynamic factor demand functions in the case of more-than-one quasi-fixed inputs and a different adjustment mechanism.

The assumption of static expectations seems to be very restrictive. The model could be extended to incorporate different assumptions about expectations. However, we should recall, here, the arguments made by Chambers and Lopez about expectations. The cost of acquiring information might be very high so that it may be "rational" to rely on static expectations. This might be true for the energy market before 1973 and even afterwards as the unpredicted and abrupt changes should have made the acquisition of related information extremely costly. Also, the ability to store inputs or outputs at a low cost in relation to the value of final commodities makes the assumption of static expectation quite sensible. We should mention here that Epstein and Denny in a similar model showed that their results were robust to alternative specification of expectations. Moreover, the assumption in our case is related to a short time series.

Now, incorporating the above assumptions and normalizing by the price of materials, P_M, we write the NRCF as:

$$\begin{aligned}(9)\quad C &= P_L\,L + P_E\,E + M = D_C\,D_{Ct}\,t \\ &+ D_E\,P_E + D_Y\,Y + D_{\dot{K}}\,\Delta K + D_K\,K_{t-1} \\ &+ \tfrac{1}{2}\,[D_{EE}\,P_E^2 + D_{LL}\,P_L^2] + D_{LE}\,P_L\,P_E \\ &+ D_{LK}\,P_L\,K_{t-1} + D_{EK}\,P_E\,K_{t-1} \\ &+ D_{LY}\,P_L\,Y + D_{EY}\,P_E\,Y + D_{L\dot{K}}\,P_L\,\Delta K \\ &+ D_{E\dot{K}}\,P_E\,\Delta K + D_{Lt}\,P_L\,t + D_{Et}\,P_E\,t \\ &+ D_{Kt}\,K_{t-1}\,t + D_{\dot{K}t}\,\Delta K\,t + D_{K\dot{K}}\,K_{t-1}\,\Delta K \\ &+ D_{YK}\,Y\,K_{t-1} + D_{Y\dot{K}}\,Y\,\Delta K + \tfrac{1}{2}\,[D_{YY}\,Y^2 \\ &+ D_{KK}\,K_{t-1}^2 + D_{\dot{K}\dot{K}}\,(\Delta K)^2]\end{aligned}$$

The internal costs of adjustment within C are connected with the term ΔK and can be written as a sub-function $G(\Delta K)$. At a stationary point $\Delta K = 0$ implies $G(\Delta K) = 0$. Moreover, we assume that the marginal costs of adjustment are also zero at $\Delta K = 0$ (i.e., $\lim_{\Delta K \to 0} G'(\Delta K) = 0$) which implies that:

$$\begin{aligned}(10)\quad \frac{\partial G}{\partial \Delta K} &= \frac{\partial C}{\partial \Delta K} = D_{\dot{K}} + D_{L\dot{K}}\,P_L \\ &+ D_{E\dot{K}}\,P_E + D_{\dot{K}t}\,t + D_{K\dot{K}}\,K_{t-1} \\ &+ D_{Y\dot{K}}\,Y + D_{\dot{K}\dot{K}}\,\Delta K = 0\end{aligned}$$

This, in turn, implies the following restrictions:

$$(11)\quad D_{\dot{K}} = D_{L\dot{K}} + D_{E\dot{K}} + D_{\dot{K}t} + D_{K\dot{K}} = D_{Y\dot{K}} = 0$$

Incorporating these restrictions in the NRCF we derive the short-run demands for variable factors by utilizing the property $\partial C/\partial P_j = v_j$

$$(12)\quad \frac{\partial C}{\partial P_L} = L = D_L + D_{Lt}\,t + D_{LL}\,P_L + D_{LE}\,P_E + D_{LY}\,Y + D_{LK}\,K_{t-1}$$

$$(13)\quad \frac{\partial C}{\partial P_E} = E = D_E + D_{Et}\,t + D_{LE}\,P_L + D_{EE}\,P_E + D_{EY}\,Y + D_{EK}\,K_{t-1}$$

$$\begin{aligned}(14)\quad M &= C - P_L\,L - P_E\,E \\ &= D_C + D_{Ct}\,t + D_K\,K_{t-1} + D_Y\,Y \\ &- \tfrac{1}{2}\,[D_{LL}\,P_L^2 + 2\,D_{LE}\,P_L\,P_E \\ &+ D_{LL}\,P_L^2] + D_{YK}\,YK_{t-1} \\ &+ \tfrac{1}{2}\,D_{YY}\,Y^2 + \tfrac{1}{2}\,D_{KK}\,K_{t-1}^2 \\ &+ \tfrac{1}{2}\,D_{\dot{K}\dot{K}}\,(\Delta K)^2 + D_{Kt}\,K_{t-1}\,t\end{aligned}$$

The optimum capital stock at the steady state (derived from equation 3 in Appendix A) takes the form:

$$(15)\quad K^*_t = \left[\left(-\frac{1}{D_{KK}}\right)(D_K + D_{LK}\,P_L + D_{EK}\,P_E + D_{YK}\,Y + D_{Kt}\,t + P_K)\right]$$

The optimal path of capital is characterized by equations (7) and (8). The adjustment coefficient given by (8) takes the following form:

$$(16)\quad M^*_1 = -\tfrac{1}{2}\left[r - \left(r^2 + \frac{4\,D_{KK}}{D_{\dot{K}\dot{K}}}\right)^{1/2}\right]$$

and the net capital investment equation becomes:

$$\begin{aligned}(17)\quad \Delta K_t &= M^*_1\,[K^*_t - K_{t-1}] \\ &= -\tfrac{1}{2}\left[r - \left(r^2 + \frac{4\,D_{KK}}{D_{\dot{K}\dot{K}}}\right)^{1/2}\right] \\ &\cdot\left[\left(-\frac{1}{D_{KK}}\right)\cdot(D_K + D_{LK}P_L + D_{EK}P_E + D_{YK}Y + D_{Kt}t + P_K) - K_{t-1}\right]\end{aligned}$$

Equations (12)–(14) are short-run demand functions for L, E, and M while equation (17) gives the net capital accumulation. The system is non-linear and simultaneous since ΔK_t is a right-hand variable in (14) and endogenous in (17). However, as indicated by Berndt and Morrison, the system is structurally recursive as ΔK_t in (17) depends only on exogenous variables and also enters only in equation (14).

We are able to derive short and long-run elasticities with our dynamic model. Short-run elasticities are obtained when capital is fixed while long-run elasticities are derived when capital has adjusted to its long-run equilibrium value K*. Short-run own and cross-price elasticities for the variable inputs can be calculated as:

$$(18)\quad E_{v_jP_l}{}^{SR} = \left(\frac{P_l}{v_j}\right)\left(\left.\frac{\partial v_j}{\partial P_l}\right|_{K = K_{t-1}}\right)\qquad \begin{aligned} j &= L, E, M \\ l &= L, E, M, K\end{aligned}$$

The long-run own and cross-price elasticities for the variable inputs can be derived as:

$$(19)\quad E_{v_jP_l}{}^{LR} = \left(\frac{P_l}{v_j}\right)\left(\left.\frac{\partial v_j}{\partial P_l}\right|_{K = K_{t-1}} + \frac{\partial v_j}{\partial K^*}\cdot\frac{\partial K^*}{\partial P_l}\right)\qquad \begin{aligned} j &= L, E, M \\ l &= L, E, M, K\end{aligned}$$

The long-run own and cross-price elasticities for capital can be calculated as:

$$(20)\quad E_{KP_l}{}^{LR} = \left(\frac{P_l}{K^*}\right)\left(\frac{\partial K^*}{\partial P_l}\right)\qquad l = K, L, E, M$$

The primary sources of our cross-sectional (state) time-series data were the Census of Manufacturers (CM) and the Annual Survey of Manufacturers (ASM). We developed input prices and quantities for each state-level two-digit manufacturing sector for each year 1971 through 1973.[3]

Labor quantity was hours worked by all employees. We adjusted labor for quality along three dimensions: school years completed, age, and sex, to avoid any bias in the substitution possibilities.[4] Labor price was the implicit

[3] A more extensive analysis can be found in Vlachou, pp. 133–147.

[4] A low price of labor associated with low labor quality will not necessarily lead to a substitution of labor for other inputs. We should mention, here, that although we gave attention to the quality of labor only, other inputs, including energy, may differ in quality. Our special interest in labor can be explained on historical grounds. A number of regional studies have concentrated on explaining the North-South wage differentials (see, for example, Scully, and Gallaway); labor quality was found to be an important factor accounting for these differentials and this result led us to give special attention to labor quality. Moreover, we should also note that it is hard to collect information on the quality of other inputs; the financial and time costs of gathering such information were beyond the scope of this study.

price obtained by dividing the total payroll by the quantity of labor.

We developed state-level prices for aggregate energy using the approach of Pindyck; a translog price aggregator was applied to the prices of different energy types.

Reliable prices for materials do not exist for different states of the U.S. and, thus, we were forced to assume that materials prices were equal to unity across all states. Since relative prices are required in the estimating equations this did not lead to econometric problems; it did cause us to exclude all data for Alaska and Hawaii, however, for which the assumption is too unrealistic.

Capital service prices were developed with the standard formulas.[5] The service price of capital varies across states due to differences in state property taxes and state corporate profits taxes, and to some extent to regional rates of return as reported by the Federal Reserve. Capital stocks were based on data for "book value of depreciable assets" for state two-digit sectors for 1976,[6] together with annual investment data taken from the Census and Annual Surveys. Gross stocks were converted to net stocks by using BLS data on net stocks for 1976. The standard perpetual inventory formula was used to obtain estimates of net capital stocks for earlier years.

Output data were constructed from shipments adjusted for beginning and ending inventories of finished goods. Output was measured at the level of average firm (i.e., we divided output by the number of firms), using the number of firms in each state two-digit sector as of 1972.[7]

Identification of regions was the subject of an elaborate pre-test. Our objective was to aggregate states with similar sectoral production functions. Criteria used, in addition to regions as defined by the Census Bureau, were age of capital stock, and relative input prices, with and without contiguity imposed.[8] Based on these criteria, seven regional tests were conducted and the number of regions under each test was four. A static translog cost function was assumed to represent the homothetic production function and data for the 74–76 period was used for its estimation. Sectoral models were estimated first for each of the four regions and second for all the observations together. A Chow test was conducted to determine if the regions defined under each one of the seven criteria could be pooled together. Rather surprisingly, the Census designations gave the greatest number of sectors that differ statistically in their production structure, and so are used here. Geographical proximity may indicate, besides the interaction of shared economic characteristics, similar cultural, sociological and climatological conditions. Because of degrees of freedom problems we had to work with only three regions. Our Northeast region consists of New England, Middle Atlantic and East North Central; the Southeast contains South Atlantic and East South Central regions; the West includes all other states.

As constituted, the Northeast (NE) produced 49 percent of total U.S. value added in manufacturing in 1972, the West (W) produced 35 percent and the Southeast (SE) produced the remaining 17 percent.

Because some state-sectors were not widely represented in certain regions, we chose to include only 12 two-digit sectors in our final analysis. These were arrived at by determining the nine largest in each region which, since these were not the same in each region, gave a total of 12 sectors.

In Table 1 in Appendix B we give a picture of the industrial structure of each region basically in terms of sectoral shares of total value added produced in each region in 1972. These different industrial structures have been historically associated with different patterns of capital accumulation. Regional differences in input prices faced by each sector are shown in Table 2 in Appendix B. The price of labor is the lowest in the SE for all but one sector, and highest in the NE for all but three of the 12 sectors. Similarly, the NE faces the highest energy prices in general, while the W has the lowest. The service price of capital shows less regional variation, but with some tendency for it to be higher in the SE than in the other two regions.

Results

Using cross-sectional (state) data for three years (1971–1973) we estimated the parameters of our simultaneous equations system for each of our twelve two-digit sectors in each of

[5] See, for example, Berndt.

[6] Provided, on special contract, by the Bureau of the Census.

[7] We assumed, therefore, that the number of firms changes only slowly.

[8] See Vlachou for details.

the three regions. For the estimation we used the Zellner's "seemingly unrelated" regression method of the TSP program. Since the error terms of the estimating equations are assumed to be correlated we work within the generalized least squares framework. Parameter estimates, not presented here but available on request, are consistent and asymptotically efficient. The overall evaluation of the model is fairly good as a great number of parameter estimates are statistically significant at 95 percent level of significance.[9]

Figure 1 presents the short-run and long-run own price elasticities. There are several positive own prices elasticities; however, the majority of them are close to zero. Positive own elasticities can be explained by either a non-cost-minimizing behavior or a poor approximation of the cost function by a quadratic form.

Own price elasticities for labor, both short- and long-run, are relatively inelastic in the majority of the sectors. At first sight no distinct regional pattern seems to exist in labor elasticities. However, the NE concentrates six sectors (20, 24, 27, 34, 35, 37 accounting for 53.5 percent of the value added produced in the region in 1972) with the most elastic LR demand for labor. In contrast, five sectors (22, 23, 26, 28, 33 accounting for 31.6 percent of the value added produced in the SE in 1972) show most elastic LR demand for labor in the SE. These findings, in combination with importance of each region in total U.S. Manufacturing, imply that (LR) demand for labor is more elastic in the NE, a result supported also by Harper and Field.

We note with interest that the sectors with the most elastic demand for labor in the NE experience the highest labor prices out of all regions while in the SE the opposite is the case, i.e. the sectors with the most elastic demand for labor in the SE experience the lowest labor prices out of all regions. Thus, opposite historical labor price patterns seem to have produced the same result: great sensitivity to changes in labor prices. We also note with interest the small difference between short-run and long-run elasticities (exceptions that stand out are sectors: food (20) in the NE, chemicals (28) in the W, metal (34) and transportation equipment (37) in the NE).

Own price elasticities for energy show quite a dispersion. Elastic energy demand is experienced in sectors 28 and 33 in all regions; also in sectors 20 and 26 in the West and 35 and 37 in the Northeast. The West is the only region which experiences the most elastic demand for energy in as many sectors as five (20, 24, 26, 33, 37 accounting for 36.4 percent of value added of the region). We note that the West experiences the lowest energy prices in all regions in these five sectors. This implies that at least in these sectors, production structures are more responsive to energy price changes than in other regions. However, no general regional energy pattern can be discerned with confidence.

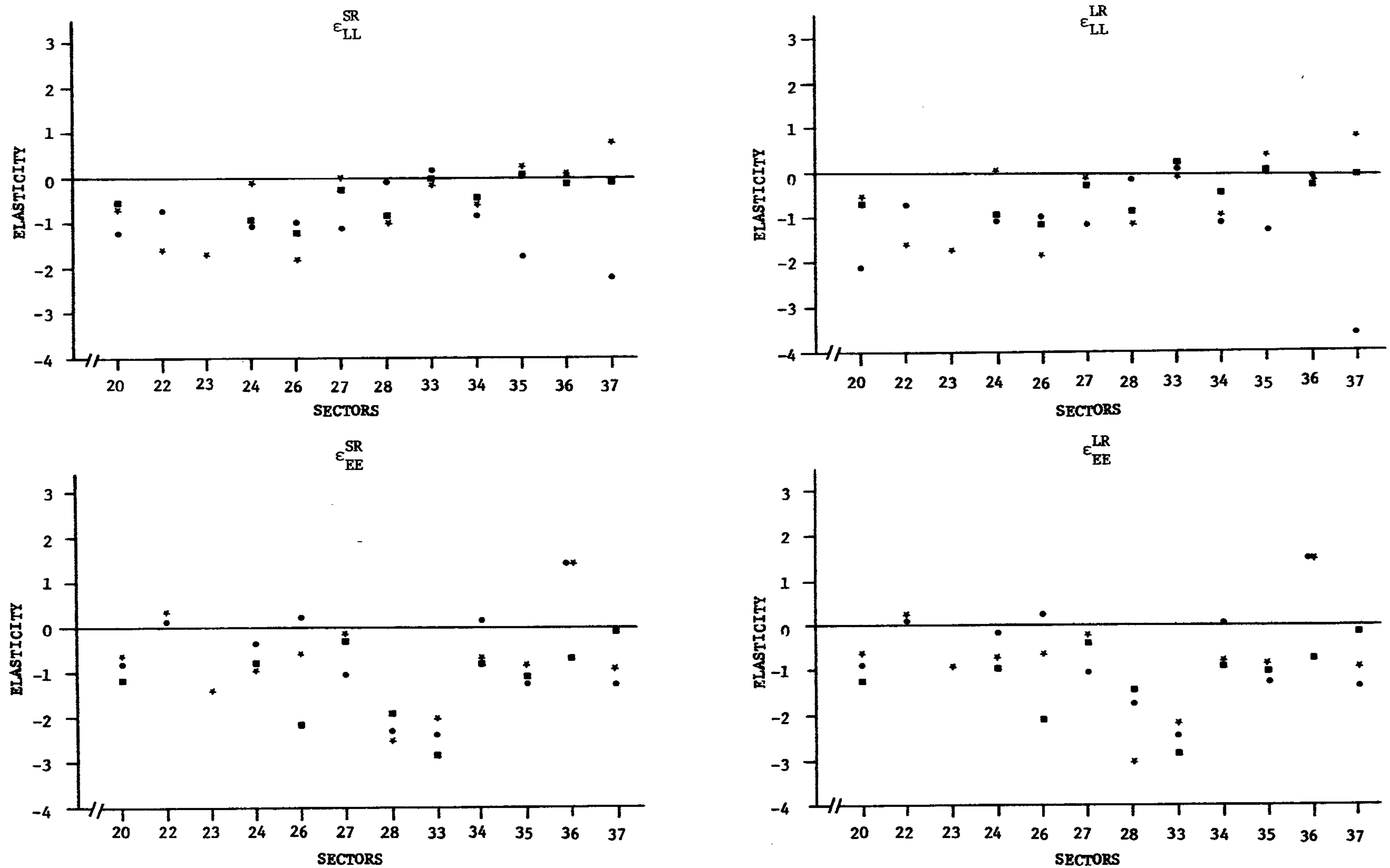
In Table 1 we provide two kinds of comparisons for the regional own price elasticities for energy. First, we compare them with aggregate U.S. elasticities estimated with this dynamic model using our data; we note that there is a great variation among regional and national own price elasticities for energy. However, these differences are more sector-specific than region-specific. This implies that energy price policy should be differentiated not only for regions but also for sectors.

Second, we compare the LR elasticities of this study with Harper and Field's elasticities for the 9 sectors for which information is available. We notice that for six sectors in the West (20, 26, 28, 33, 34, 35), five sectors in the Southeast (20, 26, 27, 28, 37), and three sectors in the Northeast (20, 28, 35) our elasticities are greater. This seems to imply that our dynamic specification captures better the long-run since it poses fewer restrictions, i.e. it provides a process for the quasi-fixed input (here capital) to adjust instead of assuming instantaneous adjustment.

Own price elasticities for materials are more concentrated and smaller, especially in the short-run, than those of other inputs. No regional pattern can be discerned.

Own price elasticities of capital are quite dispersed and a considerable number of them are positive implying an upward sloping demand for capital. A number of them are in the elastic range while sectors 28, 33 and 36 show elastic demand for capital in all regions. Regional patterns cannot be identified for capital and we should recall, here, that the service

[9] As it is known, within a generalized least squares framework the R^2 is a meaningless measure of goodness-of-fit. However, the number of significant coefficients is an indication of good performance. In our model 50.0 percent of the estimated coefficients (for the twelve sectors) are significant in the Northeast while 44.5 percent in the West and 49.2 percent in the Southeast are statistically significant at 95 percent level of significance.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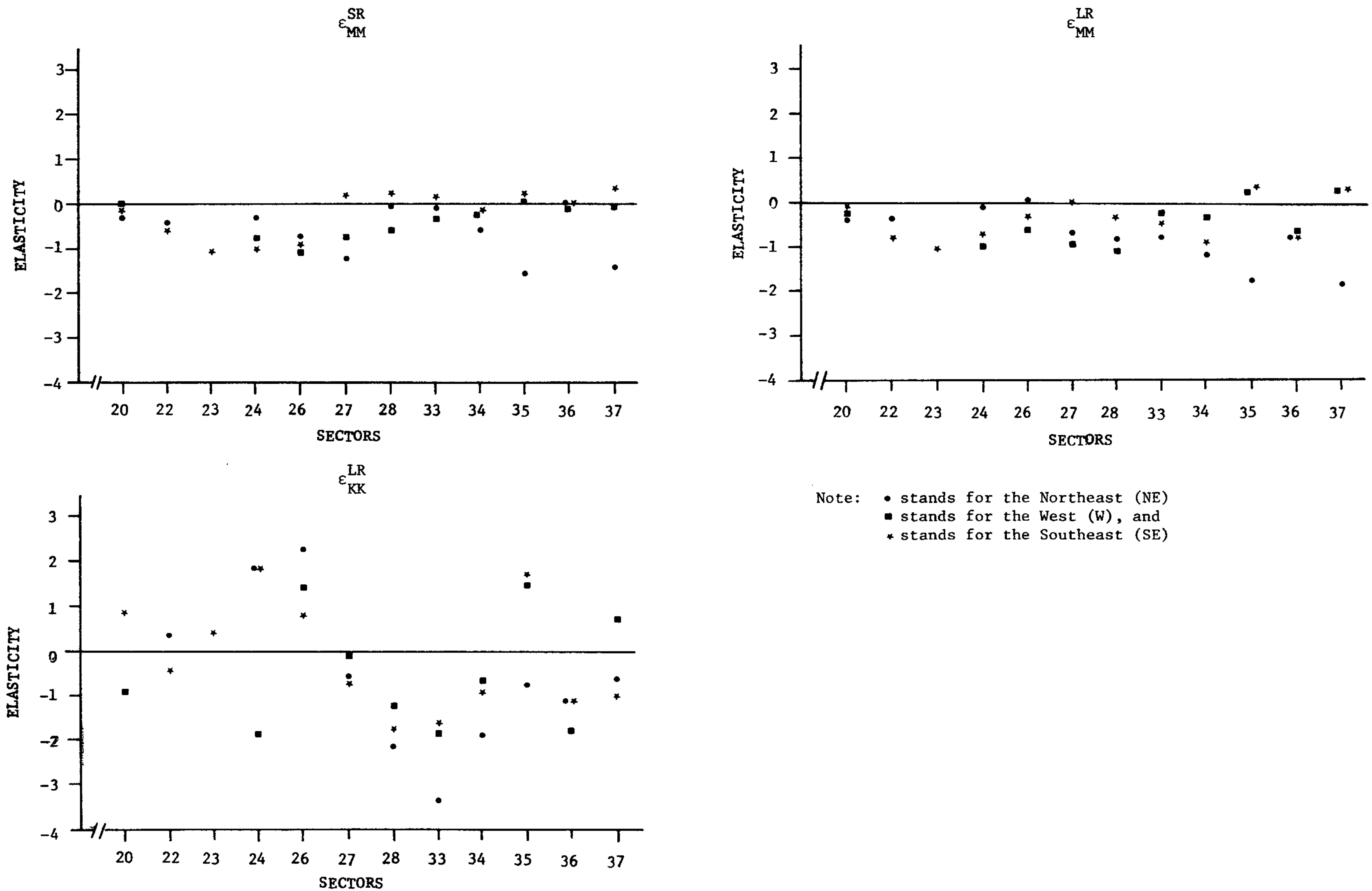
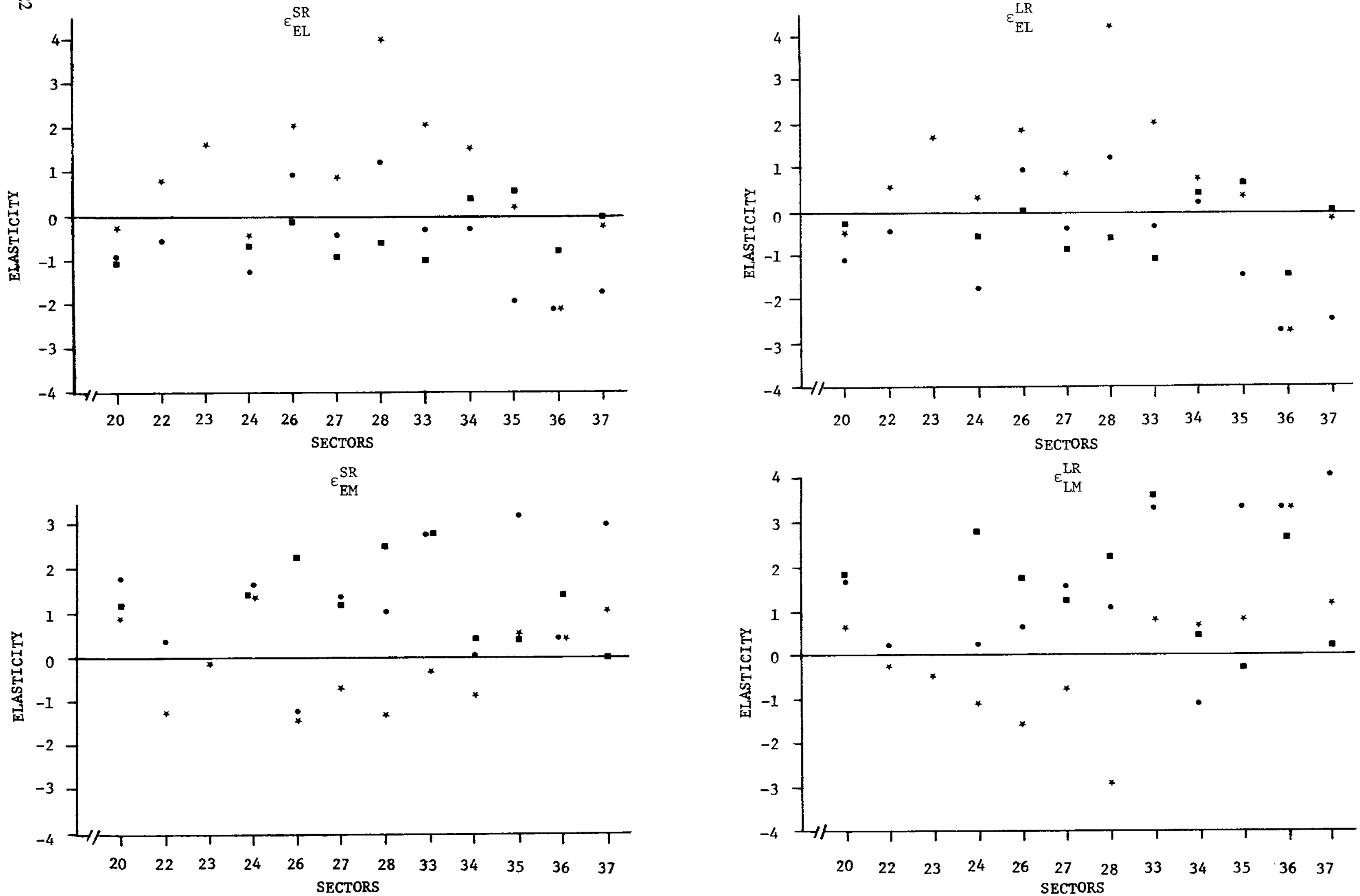


Figure 1. Short-Run (SR) and Long-Run (LR) Own Price Elasticities by Sector.



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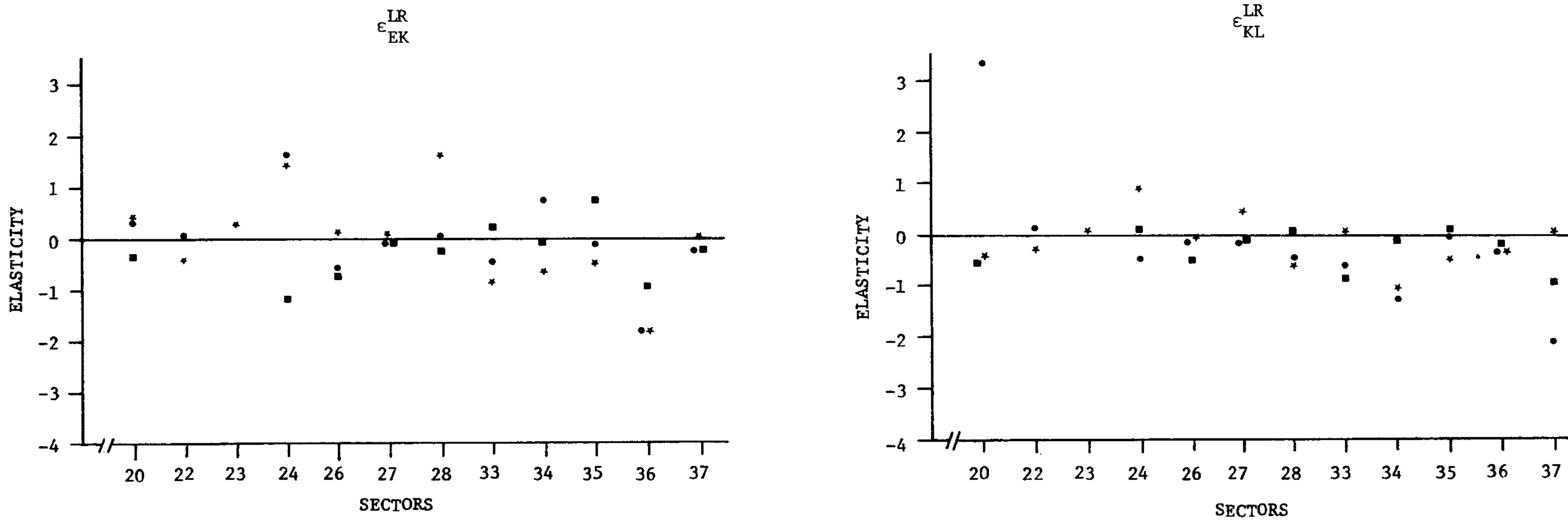

Note: • stands for the Northeast (NE), ▪ for the West (W), and * for the Southeast (SE).

Figure 2. Short-Run (SR) and Long-Run (LR) Cross-Price Elasticities by Sector.

Table 1. Own Price Elasticities for Energy—A Comparison

	This study—LR Elasticities				Harper and Field		
	U.S.	NE	W	SE	NE	W	SE
Food (20)	−1.210	−0.843	−1.208	−0.601	−0.82	−0.94	−0.27
Textiles (22)	−0.636	0.135		0.243			
Apparel (23)	−0.281			−1.450			
Lumber and Wood (24)	−1.288	−0.167	−0.957	−0.718			
Paper (26)	−0.954	0.281	−2.105	−0.593	0.13	−1.49	−0.36
Printing (27)	−0.521	−1.038	−0.388	−0.185	−1.09	0.35	−0.13
Chemicals (28)	−1.883	−2.349	−1.913	−3.029	−2.29	−1.64	−2.78
Primary Metals (33)	−1.675	−2.487	−2.850	−2.184	−2.78	−2.39	−2.62
Fabricated Metals (34)	−0.669	0.103	−0.856	−0.848	0.05	−0.54	0.61
Machinery (35)	−0.821	−1.325	−1.084	−0.827	−1.14	−0.83	−1.07
Machinery Electrical (36)	−0.415	1.146	−0.758	1.146	−0.68	−0.76	1.13
Transportation Equipment (37)	−0.703	−1.383	−0.074	−0.956	−1.75	−0.55	−0.49

price of capital also showed small regional variation.

Some significant cross price elasticities are presented in Figure 2. With respect to the energy-labor relationship both the short-run and the long-run elasticities show the majority of the sectors in the Southeast experiencing substitutability while in the West and the Northeast complementarity. To understand these findings we should recall that the price of labor is the lowest in the Southeast and the highest in the Northeast for the majority of sectors. This price structure led to such a production structure that cheap labor can easily substitute for energy in the Southeast while more expensive labor substitutes for energy with difficulty in the other two regions. We should note here that this pattern is stronger within the dynamic context than in Harper and Field's static model. The implication of these findings is that labor price can be a more effective instrument for easing the energy constraint in the SE than in the other two regions.

It should be noticed that the majority of the studies of U.S. manufacturing have found E-L substitutability, although a number of them (Denny, Fuss and Waverman; Berndt and Morrison) have found a certain degree of complementarity. Our results might indicate that substitutability is possible in the SE where the unskilled labor may outweigh the skilled labor in our aggregate labor index, while in the other two regions complementarity prevails as skilled labor may outweigh the unskilled labor. This explanation is consistent with Berndt and Morrison's reasoning that energy and unskilled labor are substitutable while energy and skilled labor are complementary.

With respect to E-M cross price elasticity, E and M are clearly substitutes in the Northeast and the West but the evidence is dividing in the SE. Thus, the SE shows the smaller substitutability while the other two regions both experience relatively high E-M elasticities in a number of sectors. Since we don't know the regional price structure for materials, we have to restrict ourselves to the energy prices in order to explain the E-M substitutability pattern. High energy prices in the Northeast and low prices in the West have produced a great sensitivity in the demand for materials with respect to energy prices in these areas. Materials substitute easily for expensive energy in the Northeast while cheap energy substitutes easily for materials in the West.

The E-K elasticities show a divided evidence in all regions and a great number of them cluster around zero. In these findings we agree with Harper & Field although there are differences in individual elasticities.

With respect to the K-L relationship, there is great evidence of complementarity; however, all these elasticities are concentrated around zero. We note with interest that Pindyck and Rotenberg in a recent study found K-L complementarity in aggregate U.S. manufacturing, a result that is in agreement with our findings at the two-digit sectors.

In Table 2 we present the adjustment coefficients which show the percentage of adjustment to long-run equilibrium that occurs in the first year. The table shows quite an instability in the adjustment process. This instability questions mostly the assumption, often made in this kind of model, of increasing mar-

Table 2. Adjustment Coefficients

	Northeast	West	Southeast	U.S.
20		.2877		
22	(.4532)	M		.1511
23	M	M	(.2843)	.3750
24			(.2075)	
26				0.0801
27		.9227	1.1244	
28	.2063	.2954	.0607	0.2256
33	.0712		.2652	
34				
35				(.1460)
36	.1241	.2861	.1241	(.2505)
37			.4041	

Note: Blanks signify negative adjustment coefficients. Parentheses signify positive adjustment coefficients due to both a positively sloped demand for capital and a decreasing marginal cost of adjustment. M indicates that the sector is missing due to inadequate degrees of freedom.

ginal costs of adjustment. However, in the cases where coefficients have been estimated a relatively slow adjustment process becomes discernible, thus supporting the dynamic specification versus the static one.

Conclusions

Our results seem to indicate that factor demands are not only region-specific but also sector-specific. This implies that energy policy should be differentiated not only by region but also by sector. Nevertheless, we have identified some regional characteristics for certain factor demands.

First, labor demand was found to be elastic in the northeast and southeast. This result in combination with the E-L substitutability in the southeast implies that labor can be an instrument for substituting away from expensive energy in the southeast. This result seems quite plausible since the southeast has a comparative advantage in the labor input.

Second, with respect to energy demand we found that the west concentrates a great number of sectors which experience the most elastic energy demand in all regions. This coupled with the E-L complementarity and a divided evidence on the E-K relationship seems to indicate that sectors that may have attracted to the region because of cheap energy are in a difficult position. They seem to have built production structures where energy is complementary to labor and to a significant extent to capital input. As energy prices increase their costs of production increase rapidly since they cannot substitute away from energy and the region might lose its comparative advantage in energy cost, given the production technology. However, materials can substitute for energy in the West and, thus, they can be used to mitigate the effect of energy price increases on production costs.

Third, the northeast experiences an elastic demand for labor and a relatively inelastic demand for energy. Moreover, energy and labor were found to be complements in the northeast while the evidence for energy and capital is divided. However, energy and materials are substitutes in the majority of the sectors. This implies that the effect of energy price increases can be mitigated by substituting mostly materials for energy.

With respect to the energy-capital relationship, which has been given so much attention in the literature, our results show a wide variation by region and sector with the exception of sector 36 where energy and capital are complements in all regions. Thus, capital input incentives to substitute away from energy should be both region- and sector-specific.

Finally, dynamic own price elasticities for energy show a greater response of energy demand to changes in energy prices than the static elasticities; this, in combination with the evidence that the adjustment process is slow, seems to speak in favor of the dynamic specification.

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Appendix A

The Hamiltonian of the minimization problem described in equation (6) of the text is:

$$(1) \quad H(x, \dot{x}, \lambda, t) = e^{-rt}[C(P, x, \dot{x}, Y, t) + ux] + \lambda\dot{x}$$

The necessary conditions for the optimum path of x(t) are:

$$(2) \quad -C_x - rC_{\dot{x}} - u + C_{\dot{x}\dot{x}}\ddot{x} + C_{x\dot{x}}\dot{x} = 0$$

where x, $\dot{x}$ subscripts denote derivatives while $\ddot{x}$ is the second partial derivative with respect to time. We note that the sufficient conditions are always satisfied since C is convex in x and $\dot{x}$.

A steady-state solution is obtained from (2) when $\ddot{x} = \dot{x} = 0$:

$$(3) \quad -C_x(P, x^*) - rC_{\dot{x}}(P, x^*) - u = 0$$

x^* is unique as long as $[-C^*_{xx} - rC^*_{x\dot{x}}] \neq 0$, where the star means that C_{xx} and $C_{x\dot{x}}$ are evaluated at the point x^* and $\dot{x} = 0$.

Treadway (1971, 1974) has linked this model to the flexible accelerator or partial adjustment models by showing that $\dot{x}$ can be generated from (2) and (3) as an approximate solution to the multivariate linear differential equation system:

$$(4) \quad x = M^*(x^*, r)[x^* - x]$$

where M^* is a stability matrix satisfying the condition:

$$(5) \quad -C^*_{\dot{x}\dot{x}}M^{*2} - rC^*_{x\dot{x}}M^* + C^*_{xx} + rC^*_{x\dot{x}} = 0$$

In the case of only one quasi-fixed input (4) and (5) become equations (7) and (8) of the text.

Appendix B

Table B1. Sectoral Shares (Percent of Regional Total) of Total Value Added, Three Regions, 1972

Sector	Northeast	Southeast	West
20	7.53	9.53	17.14
22	1.72	12.05	.67
23	3.69	5.96	1.79
24	6.73	3.89	4.05
26	3.07	4.87	2.57
27	6.49	3.94	3.70
28	8.20	3.81	3.00
33	8.99	4.95	2.93
34	9.77	4.66	5.93
35	11.80	9.45	8.04
36	4.82	7.43	5.16
37	11.19	6.83	9.71
All Other Sectors	16.00	22.63	35.31
Total Manufacturing	100.00	100.00	100.00

Source: Census of Manufacturers, Area Statistics, Volume I, 1972.

Table B2. Input Prices, 1972, Twelve Two-Digit Manufacturing Sectors

	Labor[a]			Energy[b]			Capital		
Sector	NE	SE	W	NE	SE	W	NE	SE	W
20	4.18	3.37	3.84	2.08	1.59	1.41	.17	.14	.16
22	3.37	2.89	3.02	2.22	1.61	1.32	.17	.18	.17
23	3.03	2.50	2.68	2.15	1.52	1.47	.16	.17	.16
24	3.62	3.09	3.60	1.92	1.54	1.33	.18	.19	.18
26	4.31	4.25	4.63	2.08	1.56	1.39	.17	.18	.18
27	4.71	4.34	4.39	2.14	1.57	1.42	.16	.17	.17
28	5.05	4.55	4.86	2.12	1.54	1.43	.18	.19	.18
33	5.68	4.54	4.74	2.12	1.54	1.52	.18	.19	.18
34	3.86	4.32	4.15	1.54	2.26	1.66	.18	.17	.18
35	4.81	4.26	4.59	2.14	1.57	1.44	.18	.19	.18
36	4.55	4.02	4.16	2.13	1.54	1.43	.17	.18	.17
37	5.42	4.49	4.86	2.07	1.53	1.47	.18	.19	.17

[a] Quality adjusted; see text; price is dollars per hour.
[b] Dollars per 1,000 BTU's.