Identifying Factor Substitution and Energy Intensity in the U.S. Agricultural Sector

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Selected Paper prepared for presentation for the 2015 Agricultural & Applied Economics Association and Western Agricultural Economics Association Annual Meeting, San Francisco, CA, July 26-28.

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1 Introduction

Farm production in the United States has continued to expand due to an increase in productivity growth over the last few decades. According to the Economic Research Service of the United States Department of Agriculture (USDA-ERS), the annual growth rate of the total factor productivity (TFP) was more than 1.4% between 1948 and 2011, which contributed to substantial increases in agricultural outputs. On average, agricultural outputs increased at an annual rate of 1.5%, and the use of production factors grew at an annual rate of less than 0.1%. The growth of production factors has been remarkably stable, but the composition of production factors has changed over the same period. While the U.S. agricultural sector decreased the amount of labor by 78% and land by 26%, the sector increased the amount of capital and intermediate factors (e.g., energy, chemicals, purchased services, seed, and feedstock) by 140% and 65%, respectively (Wang and Ball, 2014). The contribution of capital and intermediate factors to agricultural output growth has been offset by the negative impact of labor and land on agricultural output growth.

While the composition of production factors has shifted from labor and land to capital and intermediate factors, energy is of great interest among intermediate factors because agricultural production is sensitive to energy prices (Pelletier et al., 2011; Sands et al., 2011; Beckman et al., 2013). The U.S. agricultural sector currently uses about 800 trillion British thermal units of energy according to the U.S. Energy Information Administration (EIA), and the use of energy in agricultural production is typically categorized into two

types. The first is direct energy use through the combustion of diesel, electricity, propane, natural gas, and renewable fuels, and the second is indirect energy use through the application of energy-intensive factors such as fertilizers and pesticides (Pelletier et al., 2011; Sands et al., 2011; Beckman et al., 2013). However, energy intensity dramatically decreased between 1948 and 2011 despite the direct and indirect use of energy (Figure 1). The cost share of energy nearly doubled over this period (Wang and Ball, 2014), but the ratio of energy to output decreased, showing that substantial increases in energy prices contributed to the increased cost share of energy in the U.S. agricultural sector.

The reduced intensity of energy use is a striking feature of the U.S. agricultural sector. The changes in energy intensity could be explained either by advances in energy efficiency or by structural changes in output composition (Welsch and Ochsen, 2005; Wing, 2008). Specifically, factor substitution or biased technological change could have reduced energy intensity by improving energy efficiency. Since changes in energy market conditions (e.g., energy prices) affect production costs, and in turn, the profits of agricultural producers (Canning et al., 2010; Wang and McPhail, 2014; Ball et al., 2015), the U.S. agricultural sector might have increased capital investment in energy-saving technologies to counter high and volatile energy prices. In addition, structural changes could have contributed to a reduction in energy intensity by adjusting output composition. As crop and livestock production systems require different energy intensities, changes in output composition might have led to the reduced energy intensity.

However, in the literature, there has been little attention paid to the reasons for the reduced intensity of energy use in the U.S. agricultural sector. Given that energy is an important production factor in growing crops and livestock, it is crucial to investigate empirically whether technological advances in energy efficiency have occurred in U.S. agricultural sector to reduce energy intensity. The objective of this study is three-fold. First, it aims to explore the factor demand system of the U.S. agricultural sector. As many forecasts for substitution-augmenting technological changes are based on empir-

ically estimated elasticities of factor substitution or price elasticities of factor demand (Apostolakis, 1990; Thompson and Taylor, 1995), this study focuses on substitution possibilities between energy and non-energy factors. Second, this study attempts to identify the factors that determine energy intensity in the U.S. agricultural sector. It decomposes energy intensity changes into various driving forces such as changes in budget, factor substitution, output, and technology. Lastly, this study examines regional differences in factor substitution and energy intensity. The estimates across ten production regions are compared to provide implications for increasingly scarce and volatile energy factors in different production regions.

2 Methods

2.1 Translog Cost Model

The translog cost model is widely used to examine factor substitution possibilities (Berndt and Wood, 1975; Griffin and Gregory, 1976; Özatalay et al., 1979; Berndt and Wood, 1979; Pindyck, 1979; Ray, 1982; Thompson and G., 1995; Frondel and Schimdt, 2002; Roy et al., 2006; Koetse et al., 2008; Kim and Heo, 2013; Tovar and Iglesias, 2013) The translog cost model in this study is constructed by a certain assumption about production structure in the agricultural sector. Following Pindyck (1979), I assume that the major production factors such as capital (K), energy (E), and labor (L) are weakly separable from materials. On the basis of this assumption, a second-order approximation to an arbitrary cost function yields a non-homothetic translog factor cost function, which is written as

$$\ln C_t = \beta_0 + \sum_{i=1}^{n} \beta_i \ln P_{it} + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} \ln P_{it} \cdot \ln P_{jt} + \beta_y Y_t + \frac{1}{2} \beta_{yy} (\ln Y_t)^2$$
$$+ \beta_t T_t + \frac{1}{2} \beta_{tt} T_t^2 + \sum_{i=1}^{n} \beta_{iy} \ln P_{it} \cdot \ln Y_t + \sum_{i=1}^{n} \beta_{it} \ln P_{it} \cdot T_t + \beta_{yt} \ln Y_t \cdot T_t \tag{1}$$

where C_t is total cost; P_{it} is the price of factor i for $i = K, E, L$; Y_t is the level of output; T_t denotes a time trend to capture technological change. In addition, β's are unknown parameters. By Shephard's Lemma, the conditional factor demand functions are derived by differentiating the cost function specified in Equation (1) with respect to factor prices. The factor share equations are given by

$$S_{it} = \beta_i + \sum_{j=1}^{n} \beta_{ij} \ln P_{jt} + \beta_{iy} \ln Y_t + \beta_{it} \ln T_t \tag{2}$$

where S_{it} denotes the cost share of factor i for $i = K, E, L$. In Equation (1), β_i and β_{ij} represent distribution and substitution parameters, respectively (Christensen et al., 1973). The distribution and substitution parameters obey the regularity conditions so that the cost function satisfies the restrictions corresponding to a well-behaved production function. Since the shares must add to one, an adding-up condition, $\sum_i \beta_i = 1$, is imposed on the distribution parameters. For the substitution parameters, linear homogeneity in factor prices requires $\sum_j \beta_{ij} = 0$ for $i, j = K, E, L$, and symmetry in factor prices requires $\beta_{ij} = \beta_{ji}$ for all $i \neq j$. In addition, β_{iy} and β_{it} measure output composition bias and technology bias, respectively. Additional adding-up restrictions are required to be $\sum_i \beta_{it} = 0$ and $\sum_i \beta_{iy} = 0$.

From the estimated parameters, the price elasticities of factor demand are obtained to examine substitution possibilities between any two factors. The elasticity of the demand for factor i with respect to the price of factor j is calculated by

$$
\begin{aligned}
\eta_{ii} &= \frac{\beta_{ii}}{\bar{S}_i} + \bar{S}_i - 1 \\
\eta_{ij} &= \frac{\beta_{ij}}{\bar{S}_j} \qquad\qquad \text{for } i \neq j
\end{aligned}
\tag{3}
$$

where $\bar{S}_i$ is the average cost share of factor i for $i = K, E, L$. The cross-price elasticities measure substitutability or complementarity. A positive η_{ij} indicates that factors i and j are substitutes, while a negative η_{ij} represents that they are complements.

2.2 Decomposition of Energy Intensity

Following Welsch and Ochsen (2005), I decompose energy intensity into various influences such as budget change, factor substitution change, output change, and technological change. The decomposition of energy intensity is commonly used to examine the determinants of energy intensity (Kratena, 2007; Ma et al., 2008, 2009a,b; Zha et al., 2012). Energy intensity at time t (e_t) is written as

$$
e_t = \frac{E_t}{Y_t} = \frac{P_{Yt}}{P_{Et}} S_{Et} \tag{4}
$$

where P_{Yt} is the output price, P_{Et} is the energy price, and S_{Et} is the energy share in total cost function at time t. From the estimated energy share $\left(\hat{S}_{Et}\right)$, the estimated energy intensity ($\hat{e}_t$) is decomposed as

$$
\begin{aligned}
\hat{e}_t = &\left(\frac{P_{Yt}}{P_{Et}}\hat{\beta}_E\right) + \left(\frac{P_{Yt}}{P_{Et}}\hat{\beta}_{EK} \ln P_{Kt}\right) + \left(\frac{P_{Yt}}{P_{Et}}\hat{\beta}_{EE} \ln P_{Et}\right) + \left(\frac{P_{Yt}}{P_{Et}}\hat{\beta}_{EL} \ln P_{Lt}\right) \\
&+ \left(\frac{P_{Yt}}{P_{Et}}\hat{\beta}_{EY} \ln P_{Yt}\right) + \left(\frac{P_{Yt}}{P_{Et}}\hat{\beta}_{ET} \ln T_t\right)
\end{aligned}
\tag{5}
$$

where the decomposition of energy intensity includes six terms. Each term in parenthesis is represented by $\hat{e}_{Bt}$, $\hat{e}_{Kt}$, $\hat{e}_{Et}$, $\hat{e}_{Lt}$, $\hat{e}_{Yt}$, and $\hat{e}_{Tt}$, respectively. The first term ($\hat{e}_{Bt}$) measures the extent to which energy prices affect energy intensity at a given energy cost share, which represents the budget effect on energy intensity. The second through fourth terms ($\hat{e}_{Bt}, \hat{e}_{Kt}$, and $\hat{e}_{Et}$) capture the factor substitution effects on energy intensity. In addition, the fifth term ($\hat{e}_{Yt}$) measures the output effect on energy intensity, while the sixth term ($\hat{e}_{Tt}$) indicates the effect of technological change on energy intensity.

Based on the decomposition specified in Equation (5), I measure how changes in budget, factor substitution, output, and technological effects contribute to energy intensity changes. The rate of change in energy intensity is written as

$$\begin{aligned}\frac{\Delta\hat{e}_t}{\hat{e}_t} = &\left(\frac{\Delta\hat{e}_{Bt}}{\hat{e}_{Bt}}\frac{\hat{e}_{Bt}}{\hat{e}_t}\right) + \left(\frac{\Delta\hat{e}_{Kt}}{\hat{e}_{Kt}}\frac{\hat{e}_{Kt}}{\hat{e}_t}\right) + \left(\frac{\Delta\hat{e}_{Et}}{\hat{e}_{Et}}\frac{\hat{e}_{Et}}{\hat{e}_t}\right) + \left(\frac{\Delta\hat{e}_{Lt}}{\hat{e}_{Lt}}\frac{\hat{e}_{Lt}}{\hat{e}_t}\right) \\ &+ \left(\frac{\Delta\hat{e}_{Yt}}{\hat{e}_{Yt}}\frac{\hat{e}_{Yt}}{\hat{e}_t}\right) + \left(\frac{\Delta\hat{e}_{Tt}}{\hat{e}_{Tt}}\frac{\hat{e}_{Tt}}{\hat{e}_t}\right)\end{aligned} \tag{6}$$

where $\Delta\hat{e}_t/\hat{e}_t$ is the rate of change in aggregate energy intensity, and $\Delta\hat{e}_{it}/\hat{e}_{it}$ denotes the rate of change in each attribute for $i = B, K, E, L, Y, T$. In addition, $\hat{e}_t$ and $\hat{e}_{it}$ indicate energy intensity in a baseline year. The decomposition in Equation (6) indicates the long-term change in energy intensity. The positive sign of the term on the right side of in Equation (6) indicates that the attribute contributes to an increase in energy intensity, but the negative sign represents that the attribute contributes to a decrease in energy intensity.

3 Results

3.1 Data and Estimation Results

Data are obtained mainly from the Agricultural Productivity published by the USDA-ERS. The data contain the estimates of the growth and relative levels of productivity across 48 states for the period from 1960 to 2004. Since the data also include the indices of relative prices and implicit quantities of inputs and outputs, state-level data are constructed for the prices and quantities of capital, energy, and labor, and output. In addition, the 48 states are grouped into ten production regions according to geographic location of production defined by the USDA-ERS, which allows to reflect similarities in agricultural production (Table 1).

The ten regions are classified into Pacific, Mountain, Northern Plains, Lake States, Corn Belt, Southern Plains, Delta States, Southeast, Appalachian, and Northeast (Barton, 1961). It is typically considered that grains such as corn and soybeans are grown in the Corn Belt, Northern Plains, and Southern Plains, oil production is concentrated in the Southeast and Delta States, and fruits and vegetables are grown mainly in the Southeast, Mountain and Pacific regions. Moreover, beef production is clustered into the Corn Belt and Northern Plains, dairy production is focused in the Northeast, Lake States, and Corn Belt, and poultry production is concentrated in the Southeast region. Based on the regional classification, Figure 2 presents that energy intensity has decreased over the period from 1960 to 2004. The patterns of decreasing energy intensity are similar within each production region, showing that the states included in a production region have common factors that reduce energy intensity.

Following Pindyck (1979), the model specified in Equation (2) is estimated by using pooled time-series data for a cross-section of 48 states. The model is also estimated by pooling the states separately to compare the estimates between the ten production regions.

The iterative seemingly unrelated regression technique is used in the estimation procedure, which ignores serial correlation in the error term (autocorrelation) but accounts for error correlations across equations (Pindyck, 1979). Since the parameters are assumed to vary across ten regions, state dummy variables are added to Equation (2). The estimation results are presented in Table 2. The estimates are obtained by imposing both symmetry and homogeneity restrictions in factor prices on the share equations.

3.2 Factor Substitution

The estimated parameters presented in Table 2 are used to calculate the price elasticities of factor demand based on Equation (3). The price elasticities of factor demand reported in Table 3 are evaluated at the average factor shares. In the estimated price elasticities of factor demand, all own-price elasticities are negative and statistically significant, showing that the three factors are responsive to their own price changes. While energy demand is more elastic than the other factors, labor demand is the most inelastic. At the national level, for instance, a 1% increase in the own prices reduces the demand for capital, energy, and labor by 0.78%, 1.05%, and 0.32%, respectively. The differences in the extent to which factor demand responds to its own price are relatively small for each region. Specifically, the absolute values of the own-price elasticities of energy demand range from 0.78 (Lake States) to 1.16 (Delta States). Those of capital demand vary from 0.67 (Northern Plains) to 0.87 (Pacific), and those of labor demand vary from 0.27 (Northeast) to 0.38 (Northern Plains).

Moreover, the estimates presented in Table 3 reveal significant substitution possibilities among the three factors, while the demand for capital, energy, and labor is inelastic across regions with respect to the price of the other factor. Concerning the relationships between capital and energy, the results show substitutable or complementary relationships between capital and energy across regions. At the national level, there is a substitutable

relationship between capital and energy, but the extent to which capital substitutes for energy (0.04) is less than which energy substitutes for capital (0.17). However, the estimates for the regions show different substitution possibilities between capital and energy. While statistical evidence shows a complementary relationship between capital and energy in Northeast (-0.02), it reveals that the substitution of capital for energy is implied by the results for Corn Belt (0.05), Northern Plains (0.02), Southeast (0.07), Delta States (0.10), and Southern Plains (0.08). The substitution of capital for energy implies that an increase in energy prices contributes to capital intensiveness in these regions, but the extent to which capital is invested in manual operation, mechanical, and automated production processes is relatively small for each region.

On the other hand, there exist substitutable relationships between labor and energy across regions. At the national level, the extent to which labor substitutes for energy (0.07) is also less than which energy substitutes for labor (0.87). The extent to which the U.S. agricultural sector replaces energy with labor is relatively small, but statistical evidence indicates that a rise in energy prices is more likely to increase labor intensiveness rather than capital intensiveness. The estimates for all regions also show consistent results regarding substitutable relationships between labor and energy, but the demand for labor with respect to energy prices is inelastic with a range between 0.06 (Northeast) and 0.10 (Mountain).

Interestingly, substitution possibilities for capital-energy exist at the regional level rather than at the national level, but those for labor-energy exist at the regional and national levels. Moreover, the extent to which labor substitutes for energy is greater than which capital substitutes for energy despite the small differences in the estimated elasticities. Statistical evidence implies that the U.S. agricultural sector is more likely to increase labor in response to an increase energy prices rather than to increase capital investment in energy efficiency. This also demonstrates that there have been less incentive for the U.S. agricultural sector to increase capital investment in energy efficiency.

3.3 Energy Intensity

The decomposition ascertains the driving forces of energy intensity in the U.S. agricultural sector and explains regional variations in energy intensity. While energy intensity is decomposed into budget, substitution, output, and technological effects, the rate of change in energy intensity investigates how the driving forces influence changes in energy intensity between 1960 and 2004. Table 4 reveals the decomposition results of energy intensity changes based on Equation (6). The estimated energy intensity at the national level decreased by about 39.1% over the period from 1960 to 2004, which was driven mainly by the budget effect (46.0%). The patterns of changes in energy intensity are similar across regions. The estimated energy intensity at the regional level shows a decrease in energy intensity over the period, which ranges from 29.5% (Mountain) to 59.2% (Delta States). The same driving forces of energy intensity are also found at the regional level with variations. While all regions decreased their energy intensity, the largest budget effect occurs in the Southern Plains (77.7%), and the smallest occurs in Mountain (35.2%). Statistical evidence implies that the U.S. agricultural sector has reduced energy intensity because agricultural producers have not afford to bear increasing energy costs under their energy budget constraints.

On the other hand, factor substitution effects have little influence on the reduced energy intensity at the regional and national levels. While the substitution effect of capital investment on energy use is not likely to reduce energy intensity across regions, the substitution of labor for energy reduces energy intensity occurs only in Northeast and Mountain. It is evident that the U.S. agricultural sector has not substituted capital or labor for energy to decrease energy intensity in response to increasing energy prices over the period. Statistical evidence also indicates that output effects have increased energy intensity across regions. Positive output effects show that an increase in agricultural production requires more energy, and in turn, raises energy intensity, ranging from 6.1%

(Mountain) to 33.8% (Southern Plains). However, unlike the output effects, there has been little technological improvement to reduce energy intensity across regions. The direction of technological improvement is from energy-intensive to energy-saving technology (e.g., Corn Belt, Southeast, Southern Plains, and Pacific regions), but the magnitudes are not enough to reduce energy intensity.

Consequently, statistical evidence represents that technological changes and innovative activities have not contributed to the reduced energy intensity. While agricultural output growth appears to require more energy use, the U.S. agricultural sector has not invested capital in energy efficiency or not pursued technological improvement to reduce the dependence in energy. The substitution and technological effects differ across regions, but the extent to which their effects reduce energy intensity is not apparent in the results. Statistical evidence reveals that the budget effect is the main driver of reducing energy intensity, implying that an increase in energy prices forces the U.S. agricultural sector to reduce energy intensity due to the energy budget constraint.

4 Conclusions

The inspiration for this study comes from a documented reduction in energy intensity in the U.S. agricultural sector. Since agricultural commodity prices and productivity growth are influenced by energy prices (Wang and McPhail, 2014), it is important to examine factor substitution possibilities and energy intensity changes. Given that energy is an important factor for sustainable agricultural production, not only does this study contribute to examining the responses of factor demands to changes in energy prices, it also identifies the factors that determine energy intensity. Moreover, this study provides statistical information about regional differences in factor substitution and energy intensity.

The empirical analysis in this study is performed by using the translog cost model, which offers critical values in terms of the price elasticities of factor demand. The estima-

tion results indicate that factor demand is inelastic, suggesting that agricultural producers have little flexibility in adjusting factor demand in response to rapid changes in factor prices. The substitution possibilities between capital and energy exist only at the regional leve, but those between labor and energy exist at the regional and national levels. This implies that the U.S. agricultural sector has more incentive to increase labor in response to rising energy costs rather than to increase capital investment in energy efficiency.

Based on the estimated parameters of the translog cost model, changes in energy intensity are decomposed to identify the driving forces behind the reduced energy intensity. The decomposition results indicate that the budget effect is the major driving force that decreases energy intensity. Variations exist in the budget effects across regions, but an increase in energy prices is likely to force the U.S. agricultural sector to reduce energy intensity due to the energy budget constraint. While output effects require more energy in agricultural production, there has been little factor substitution and technological improvement to reduce energy intensity in the U.S. agricultural sector. The findings in this study highlight that the reduced energy intensity is attributed only to the budget effect, implying that technological changes or innovative activities are needed in order for the U.S. agricultural sector to counter high and volatile energy prices.

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Table 1: Regional Classification

Regions	States
Northeast	Connecticut, Delaware, Maryland, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont
Lake States	Michigan, Minnesota, Wisconsin
Corn Belt	Illinois, Indiana, Iowa, Missouri, Ohio
Northern Plains	Kansas, Nebraska, North Dakota, South Dakota
Appalachian	Kentucky, North Carolina, Tennessee, Virginia, West Virginia
Southeast	Florida, Georgia, Alabama, South Carolina
Delta States	Arkansas, Louisiana, Mississippi
Southern Plains	Oklahoma, Texas
Mountain	Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming
Pacific	California, Oregon, Washington

Source: Farm Production Regions, USDA-ERS

Table 2: Estimation Results of Share Equations

	β_{KK}	β_{KE}	β_{KL}	β_{KY}	β_{KT}	β_{EE}	β_{EL}	β_{EY}	β_{ET}
U.S.	-0.005	-0.004***	0.009***	-0.075***	0.001***	-0.006***	0.010***	0.003***	0.001***
	(0.003)	(0.001)	(0.003)	(0.004)	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)
Northeast	0.020***	-0.014***	-0.006	-0.052***	0.2e-04	0.003	0.011***	0.010***	0.001***
	(0.005)	(0.003)	(0.005)	(0.007)	(0.000)	(0.002)	(0.001)	(0.002)	(0.000)
Lake States	-0.011*	-0.017***	0.006	-0.045***	0.002***	0.009***	-0.009***	0.005**	0.001***
	(0.007)	(0.003)	(0.006)	(0.010)	(0.000)	(0.003)	(0.001)	(0.002)	(0.000)
Corn Belt	0.006	-0.001	-0.005	-0.097***	0.002***	-0.005**	0.006***	-0.006***	0.001***
	(0.008)	(0.002)	(0.008)	(0.011)	(0.009)	(0.002)	(0.001)	(0.001)	(0.000)
Northern Plains	0.015**	-0.017***	0.002	-0.039***	0.001***	0.009***	0.008***	0.008***	0.001***
	(0.007)	(0.003)	(0.007)	(0.009)	(0.000)	(0.003)	(0.002)	(0.002)	(0.000)
Appalachian	-0.016**	-0.008***	0.025***	-0.156***	0.001**	-0.002	0.011***	-0.001***	0.001***
	(0.008)	(0.003)	(0.008)	(0.011)	(0.000)	(0.002)	(0.002)	(0.003)	(0.000)
Southeast	0.008	0.001	-0.009	-0.149***	0.001***	-0.012***	0.011***	-0.006	0.001***
	(0.009)	(0.004)	(0.010)	(0.013)	(0.000)	(0.003)	(0.003)	(0.003)	(0.000)
Delta States	-0.015	0.006	0.010	-0.167***	0.003***	-0.017***	0.012***	0.4e-04	0.001***
	(0.014)	(0.005)	(0.014)	(0.017)	(0.000)	(0.004)	(0.004)	(0.005)	(0.000)
Southern Plains	0.005	0.003	-0.009	-0.181***	-0.001***	-0.013***	0.010**	-0.017***	0.3-e03***
	(0.015)	(0.005)	(0.016)	(0.021)	(0.000)	(0.003)	(0.004)	(0.006)	(0.000)
Mountain	0.007	-0.017***	0.011*	-0.050***	0.3-e03*	0.003	0.014***	0.016***	0.001***
	(0.006)	(0.004)	(0.006)	(0.008)	(0.000)	(0.003)	(0.003)	(0.004)	(0.000)
Pacific	-0.011	-0.006	0.017**	-0.128***	-0.001***	-0.008**	0.014***	-0.022***	0.001***
	(0.009)	(0.005)	(0.008)	(0.012)	(0.000)	(0.004)	(0.003)	(0.004)	(0.000)

Note: Standard errors are in parentheses; The estimates for dummy variables are not reported in the results.
***Denotes statistical significance at the 1% level.
**Denotes statistical significance at the 5% level.
*Denotes statistical significance at the 10% level.

Table 3: Price Elasticities of Factor Demand

	η_{KK}	η_{EE}	η_{LL}	η_{KE}	η_{KL}	η_{EK}	η_{EL}	η_{LK}	η_{LE}
U.S.	-0.782***	-1.047***	-0.324***	0.043***	0.738***	0.173***	0.874***	0.250***	0.074***
	(0.012)	(0.020)	(0.004)	(0.006)	(0.012)	(0.023)	(0.013)	(0.004)	(0.001)
Northeast	-0.687***	-0.895***	-0.271***	-0.020*	0.708***	-0.106*	1.001***	0.213***	0.058***
	(0.023)	(0.056)	(0.007)	(0.012)	(0.021)	(0.063)	(0.028)	(0.006)	(0.002)
Lake States	-0.702***	-0.776***	-0.324***	-0.020	0.721***	-0.103	0.879***	0.262***	0.062***
	(0.026)	(0.054)	(0.010)	(0.012)	(0.025)	(0.063)	(0.026)	(0.009)	(0.002)
Corn Belt	-0.689***	-1.029***	-0.348***	0.052***	0.637***	0.273***	0.756***	0.284***	0.065***
	(0.026)	(0.034)	(0.013)	(0.008)	(0.027)	(0.041)	(0.024)	(0.012)	(0.002)
Northern Plains	-0.665***	-0.808***	-0.376***	0.019*	0.646***	0.070*	0.738***	0.286***	0.090***
	(0.024)	(0.033)	(0.012)	(0.011)	(0.024)	(0.040)	(0.023)	(0.011)	(0.003)
Appalachian	-0.846***	-1.007***	-0.320***	0.010	0.836***	0.047	0.960***	0.260***	0.060***
	(0.035)	(0.052)	(0.013)	(0.014)	(0.037)	(0.068)	(0.044)	(0.012)	(0.003)
Southeast	-0.752***	-1.133***	-0.275***	0.068***	0.684***	0.230***	0.903***	0.197***	0.078***
	(0.045)	(0.047)	(0.015)	(0.018)	(0.047)	(0.059)	(0.040)	(0.013)	(0.003)
Delta States	-0.821***	-1.164***	-0.346***	0.096***	0.724***	0.319***	0.845***	0.256***	0.090***
	(0.056)	(0.058)	(0.022)	(0.022)	(0.056)	(0.072)	(0.049)	(0.020)	(0.005)
Southern Plains	-0.744***	-1.121***	-0.304***	0.084***	0.660***	0.285***	0.836***	0.222***	0.083***
	(0.065)	(0.051)	(0.026)	(0.022)	(0.068)	(0.076)	(0.061)	(0.023)	(0.006)
Mountain	-0.737***	-0.884***	-0.348***	0.004	0.733***	0.012	0.872***	0.249***	0.098***
	(0.025)	(0.043)	(0.011)	(0.016)	(0.024)	(0.049)	(0.037)	(0.008)	(0.004)
Pacific	-0.867***	-1.056***	-0.297***	0.034	0.832***	0.099	0.957***	0.213***	0.085***
	(0.048)	(0.062)	(0.013)	(0.025)	(0.044)	(0.072)	(0.044)	(0.011)	(0.004)

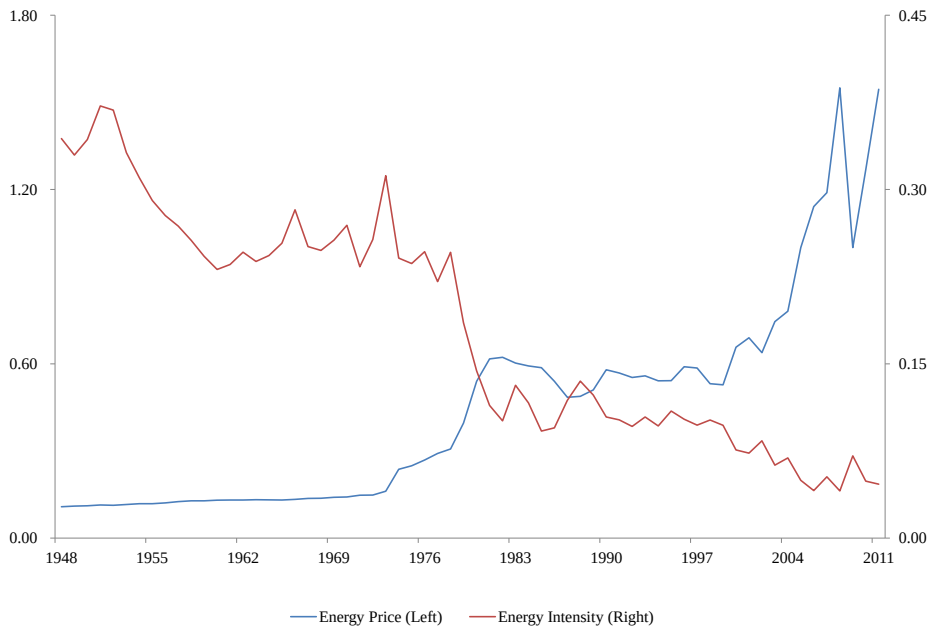
Note: Standard errors are in parentheses.
***Denotes statistical significance at the 1% level.
**Denotes statistical significance at the 5% level.
*Denotes statistical significance at the 10% level.

Table 4: Decomposition of Energy Intensity Change

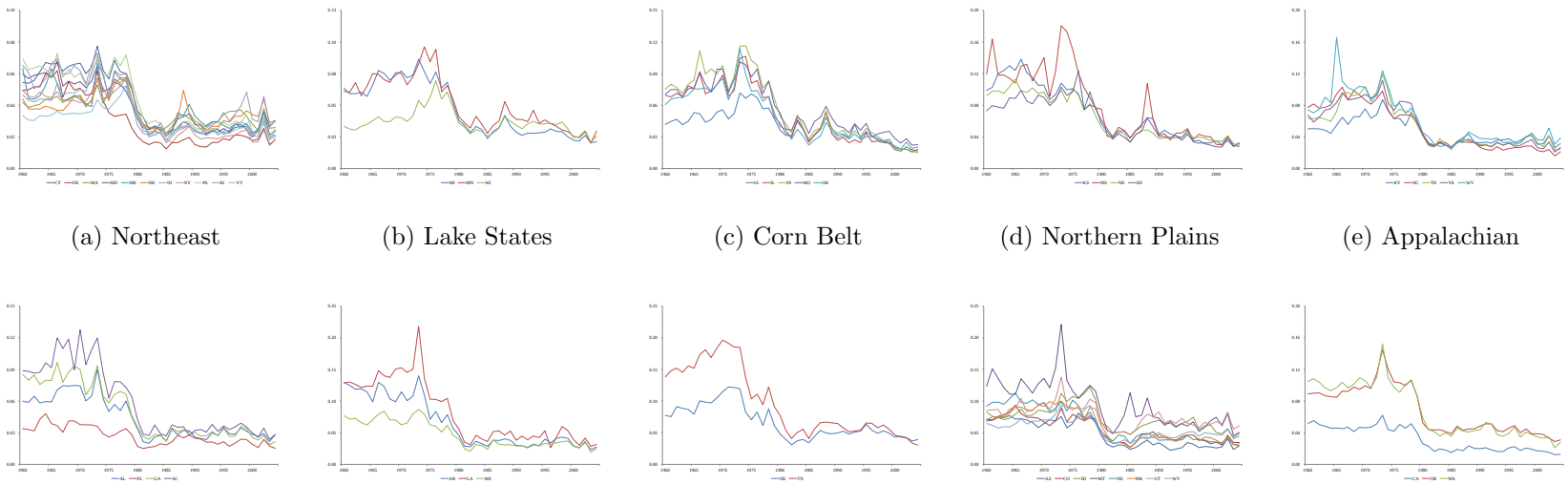
	$\frac{\Delta e}{e}$	Budget	Substitution			Output	Technology
			Capital	Energy	Labor		
U.S.	-0.391***	-0.460***	0.008	0.026	-0.027	0.061	0.001
	(0.040)	(0.083)	(0.016)	(0.054)	(0.055)	(0.105)	(0.002)
Northeast	-0.452***	-0.512***	0.011***	-0.004	-0.010***	0.063***	0.5e-03***
	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.000)
Lake States	-0.426***	-0.663***	0.122	-0.138	-0.087	0.336	0.005
	(0.064)	(0.091)	(0.089)	(0.100)	(0.066)	(0.102)	(0.003)
Corn Belt	-0.458***	-0.535***	-0.001	-0.012**	0.010***	0.081***	-0.001***
	(0.003)	(0.007)	(0.003)	(0.005)	(0.002)	(0.007)	(0.000)
Northern Plains	-0.485***	-0.765***	0.074	-0.075	-0.045	0.323***	0.003
	(0.026)	(0.104)	(0.048)	(0.046)	(0.034)	(0.107)	(0.002)
Appalachian	-0.414***	-0.457***	-0.027	-0.017	0.052	0.036	-0.001
	(0.013)	(0.040)	(0.022)	(0.018)	(0.037)	(0.054)	(0.001)
Southeast	-0.420***	-0.484***	0.002	-0.043***	0.025***	0.081***	-0.001**
	(0.011)	(0.016)	(0.006)	(0.016)	(0.009)	(0.020)	(0.000)
Delta States	-0.592***	-0.547***	0.034	-0.188	0.114	-0.002	-0.004
	(0.102)	(0.187)	(0.047)	(0.177)	(0.103)	(0.243)	(0.004)
Southern Plains	-0.463***	-0.777***	0.007	-0.059	0.029***	0.338***	-0.4e-03*
	(0.012)	(0.031)	(0.012)	(0.018)	(0.011)	(0.033)	(0.000)
Mountain	-0.295***	-0.352***	0.008**	-0.004	-0.008**	0.061***	0.3e-03***
	(0.003)	(0.005)	(0.003)	(0.004)	(0.004)	(0.006)	(0.000)
Pacific	-0.455***	-0.649***	-0.006	-0.016*	0.018***	0.197***	-0.4e-03***
	(0.005)	(0.006)	(0.005)	(0.008)	(0.004)	(0.007)	(0.000)

Note: Standard errors are in parentheses.
***Denotes statistical significance at the 1% level.
**Denotes statistical significance at the 5% level.
*Denotes statistical significance at the 10% level.

Figure 1: Energy Intensity in the U.S. Agricultural Sector, 1948-2011



Source: Agricultural Productivity in the Unites States, USDA-ERS.



(a) Northeast (b) Lake States (c) Corn Belt (d) Northern Plains (e) Appalachian

(f) Southeast (g) Delta States (h) Southern Plains (i) Mountain (j) Pacific

Figure 2: Energy Intensity in Farm Production Regions, 1960-2004