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Employment and Output Leakage under California's Cap-and-Trade Program

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RESOURCES FOR THE FUTURE

Employment and Output Leakage under California's Cap-and-Trade Program

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Abstract

To estimate the potential impact of California's Cap-and-Trade Program on the state's energy-intensive, trade-exposed manufacturing industries, this paper uses confidential plant-level Census data to model the effect of historical energy prices on plant-level output, employment, and value added, both inside and outside California, holding constant foreign energy prices. Simulation of the model for an assumed compliance cost of $10 per metric ton of carbon dioxide equivalent (CO_2) in California and zero outside the state yields 0 to 3 percent short-term (one year) impacts for almost a third of the industries studied with no output-based rebating. The largest losses are estimated in glass container manufacturing (17 percent), paperboard mills (14 percent), automobile manufacturing (13 percent), iron and steel mills and ferroalloy manufacturing (12 percent), and poultry processing (11 percent); these industries are among the most energy intensive of those studied. Estimated losses for another group of five industries are about 10 percent. These losses should be compared to an overall average one year loss of about 5.7 percent across all the California energy-intensive, trade-exposed industries studied. Simulations of higher compliance costs (up to $22 per metric ton of CO_2) result in correspondingly larger losses. Over the long run, defined as a five-year period, the results suggest that increases in California energy prices relative to those in nearby states have smaller effects than those effects seen over 1 year. Over this longer period, the largest output losses are below 1 percent, with most industries experiencing output losses below 0.1 percent, although for a variety of technical reasons the authors offer caution when interpreting the industry-specific long-run results.

Key Words: carbon price, competitiveness, leakage

JEL Classification Numbers: D21, H23, J23

Contents

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Introduction

The global nature of the climate change problem creates special challenges for regional initiatives to reduce greenhouse gas (GHG) emissions. The possibility that economic activity may relocate from areas with high regulatory costs to lower costs ones raises concerns about potentially adverse impacts of a regional GHG cap-and-trade program on industrial competitiveness, trade flows, and emissions "leakage" for emissions-intensive and trade-exposed (EITE) industries.

Emissions leakage occurs when an environmental regulation induces a shift in industrial production (and associated emissions) to less stringently regulated areas. In setting up a cap-and-trade program, California's Global Warming Solutions Act of 2006 (AB 32) directs state regulators "to minimize leakage to the extent feasible." To comply with this requirement, the California Air Resources Board (CARB) has developed a methodology to identify those industries most at risk of emissions leakage. This method, based on industry-level measures of emissions intensity and trade share, has been used to determine the initial free allocation of allowances. While these metrics provide a useful point of departure, over the long term, additional analyses and possibly additional metrics may be required to determine future levels of free allocation for each industry.

Because GHG cap-and-trade programs of the type adopted in California will raise energy prices faced by manufacturing plants in California, we use historical plant-level data to examine the effects of energy prices on the competitiveness of California plants compared with domestic competitors. The analysis focuses on the EITE sectors CARB has identified and in the first stage uses a transparent approach to model the relationship between energy prices and competitiveness. A second stage of the analysis simulates the effects of the California program on these sectors.

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The analysis is based on confidential plant-level data from the Census of Manufacturers (CMF) and Annual Survey of Manufacturers (ASM) over the 20-year period from 1989 to 2009. We estimate the effects of California and non-California energy prices on plants located both inside and outside the state. The outcomes include output, value added, and employment. For the purposes of the simulation, we assume that the Cap-and-Trade Program raises energy prices in California proportional to the compliance cost and does not directly affect energy prices outside California.[1] This report describes the statistical methodology, construction of the dataset, estimation results for both short- and long-run periods, and simulation results.

Overall, for an assumed compliance cost of $10/metric ton of carbon dioxide equivalent (CO_2)[2] in California, no output-based updating, and zero compliance cost elsewhere, we find zero or below 3 percent one-year impacts for almost a third of the California EITE industries studied, although some are more adversely affected, with the largest output losses ranging up to 17 percent. The typical industry experiences short-run employment, output, and value-added decreases of 4–6 percent. For $20/metric ton CO_2 compliance cost, the output decreases are larger, approximately on a proportionate basis.

We estimate much smaller effects for the long run than the short run, although for statistical reasons we suggest caution when interpreting the long-run results for individual industries. The largest output losses after five years are below 1 percent for the $10/metric ton of CO_2 compliance cost, and most industries experience little or no reductions in output. The typical industry experiences a long-run output increase of 0.2 percent and employment and value-added decreases of 1.3 and 0.1 percent.

These estimates reflect changes in output, employment, and value added in California relative to other regions in the United States, and they do not account for the effects of a California compliance cost on national totals. This interpretation of the simulation results is consistent with the underlying statistical model, which characterizes the effects of energy prices on economic activity at California plants relative to domestic plants located outside of California. To the extent that an increase in California energy prices would reduce total national economic

[1] "Compliance cost" is the cost of purchasing one Cap-and-Trade Program allowance or one compliance offset credit, each of which allows for the emission of 1 metric ton of carbon dioxide equivalent.

[2] "Carbon dioxide equivalent" is the the number of metric tons of CO_2 emissions with the same global warming potential as one metric ton of another greenhouse gas.

activity for a specific industry, e.g., by decreasing consumption or increasing imports, our simulation results *understate* the absolute decreases in California activity, but *overstate* emissions leakage.

Methodology

This section describes the methodology for estimating the effects of energy prices on various plant-level outcomes. We first estimate the parameters from a model that links employment, output, and value added to energy prices faced by California plants and their competitors. In the second stage we use the estimated parameters to simulate the effects of Cap-and-Trade Program-induced compliance cost increases on employment, output, and value added.

Apart from the substantial literature based on computable general equilibrium models (for example, Fischer and Fox 2012) that have examined competitiveness and leakage issues, two recently published empirical papers are particularly relevant to the analysis developed here. Focusing on differences in industry-specific employment levels across adjacent US counties, Kahn and Mansur (2013) model the effects of county-specific electricity prices and environmental regulation on an establishment's locational choices. Using a 12-year county-level cross-sectional time series panel of 21 manufacturing industries, they find that electricity prices are a significant determinant of plant location for energy-intensive industries. In contrast, the electricity price effects are modest for the typical manufacturing industry. The elasticity of employment with respect to the price of electricity (i.e., the percent change in employment caused by a 1 percent electricity price increase) ranges between –0.15 for the computer products industry and –1.17 for the energy-intensive primary metals industry.

Aldy and Pizer (2015) model the effect of energy prices on industry-specific production decisions using a 35-year panel of approximately 450 US manufacturing industries. Like Kahn and Mansur, they find that energy prices have a substantial effect on output for energy-intensive industries. Specifically, Aldy and Pizer estimate a negative output to energy price elasticity for all industries with an energy intensity (defined as the ratio of energy costs to value of shipments, multiplied by 100) greater than 0.7 percent and statistically significant elasticities when energy intensity exceeds 2.5 percent. For the most energy-intensive industries, whose intensity exceeds 15 percent, output to energy price elasticities are roughly –0.4.

These papers provide important insights into the effects of energy prices on manufacturing activity. Although we are similarly interested in the effects of energy prices on output and employment, we develop a statistical model and dataset that is specifically tailored to

analyzing the effects of California's Cap-and-Trade Program on emissions leakage. Our approach differs from theirs in several key ways. First, we conduct the analysis at the plant level and report results by six-digit North American Industry Classification System (NAICS) industry. In contrast, Kahn and Mansur use county-level data and much more aggregated industry definitions. The Aldy and Pizer study is strictly a national-level analysis. Using subnational data is essential for evaluating the effects of California's Cap-and-Trade Program on leakage, and we are able to report results based on local energy prices for a highly disaggregated set of industries.
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Second, we use multiple measures of plant-level activity, including production, value added, and employment, rather than individual outcomes analyzed in the other papers. Using multiple outcomes provides a more complete picture of the implications of compliance costs in California.

Third, and probably most important, we use a statistical model that maps directly to the effects of the Cap-and-Trade Program on energy prices inside and outside California. For a given plant competing to sell its output in the same market as other plants, we expect the plant's output, value added, and employment to depend on its costs *relative* to the costs of the competing plants. Assigning a compliance cost to GHG emissions under the Cap-and-Trade Program raises electricity and natural gas prices in California but does not directly affect prices outside the state.

The effects of these price increases on an individual manufacturing plant depend on where the plant is located. For a plant in California, energy costs increase relative to competing plants elsewhere. In contrast, for a plant located outside California, the energy prices it faces do not change, but the prices faced by its California competitors increase. The increase in energy prices in California, therefore, can create a competitive advantage for plants located outside the state.

For either type of plant, we can express its output, employment, or value added (y) as a function of the energy prices it faces and the energy prices of its competitors:

$$\ln(y) = \beta_1 s * \ln(p) + \beta_2 s * \ln(p_R) \quad (1)$$

where s is the cost share of energy, p is the energy price the plant faces, and p_R is the energy price faced by plants in other states. The energy cost share is multiplied by the energy price because a given energy price increase should have a greater effect on the outcomes for energy-intensive industries than for other industries. Due to the log-log specification, the parameter β_1 is the elasticity of the outcome with respect to the price of energy, and we expect the coefficient to be negative because a plant facing higher costs should produce less output and employ fewer workers, all else equal. The elasticity represents the percent change in the outcome variable in response to the price of energy. This particular functional form, in which we interact the cost shares with the energy prices, represents a generalization of a Cobb-Douglas production function. In the case where output is on the left-hand side of equation (1), if the plant has a Cobb-Douglas production function, the output would be directly proportional to the interaction of the cost share with the price, and β_1 would equal negative one. The parameter β_2 should be positive because an increase in the energy prices of competing plants makes the plant more competitive relative to those plants. For example, a California energy price increase would increase the competitiveness of non-California plants that compete with California plants, causing their employment, output, and value added to increase. Note that we could express the outcome variable as a function of the price of energy the California plant faces relative to the price of energy in other states (i.e., p / p_R), which would be equivalent to setting $\beta_1 = -\beta_2$ in equation (1).

Equation (1) abstracts from the effects on output, value added, and employment of other input costs besides energy, as well as product demand. We generalize this equation by adding controls and an error term to arrive at a basic regression that pools plants across industries and years:

$$\ln(y_{ijt}) = \beta_0 + \beta_{1e}^{E} s_j^{E} \ln(p_{ijt}^{E}) + \beta_{2e}^{E} s_j^{E} \ln(p_{R,ijt}^{E}) + \beta_{1g}^{G} s_j^{G} \ln(p_{ijt}^{G}) + \beta_{2g}^{G} s_j^{G} \ln(p_{R,ijt}^{G}) + \gamma_{1e}^{E} \ln(p_{ijt}^{E}) + \gamma_{2e}^{E} \ln(p_{R,ijt}^{E}) + \gamma_{1g}^{G} \ln(p_{ijt}^{G}) + \gamma_{2g}^{G} \ln(p_{R,ijt}^{G}) + \lambda_e^{E} s_j^{E} + \lambda_g^{G} s_j^{G} + \mu_1 LCOST_{ijt} + \mu_2 DGROWTH_{ijt} + \delta_j + \delta_t + \delta_{rt} + \delta_{jt} + \varepsilon_{ijt} \quad (2)$$

The dependent variable y_{ijt} is log output, value added, or employment for plant *i* in industry *j* and year *t*. Each β is the coefficient on the interaction of the electricity (E) or natural gas (G) price with the industry's cost share of that energy source in total costs. The subscripts on the β coefficients on the electricity or natural gas price faced by the plant itself (p_{ijt}^{E}) are indicated by the number '1', while the electricity or natural gas price faced by other plants in the same industry in other nearby states ($p_{R,ijt}^{E}$) are indicated by the number '2'. The γs are the coefficients on the electricity and natural gas prices without the cost share interactions. The λs are the coefficients on the cost shares without the energy price interactions. We allow for heterogeneity across industries in all of these coefficients. In the baseline case, each industry is assigned to one of five groups for electricity (e) and natural gas (g) (uppercase superscripts refer to the energy source, electricity or natural gas, and lowercase subscripts refer to the electricity or natural gas cost-share group). For example, there are five β_1^{E} coefficients, one for each group of electricity-consuming industries. We include an index for the labor costs (LCOST) faced by nearby plants in the same industry and an index for the growth in demand for the plant's products (DGROWTH). Finally, the model includes fixed effects for industry, year, census division by year, and industry byyear, as well as an error term.[3] The next section describes the variable construction in more detail.

Equation (2) is estimated for all plants in the United States in these industries, pooling observations in California and in other states. The equation is estimated by ordinary least squares (OLS). Because equation (2) uses annual data, the coefficients are interpreted as representing the short-run relationships between the independent and dependent variables—that is, the within-year effects of energy price shocks.

The coefficients of interest are the γs and the βs, which are the coefficients on the direct effects of electricity and natural gas prices, as well as the effects of the prices interacted with the industry's electricity or natural gas cost share. As mentioned above, a Cobb-Douglas production function would imply that all cost share-price interaction coefficients are equal to positive or negative one. We relax the Cobb-Douglas assumption by allowing the coefficients on the cost share-price interactions to differ across industries.

In the preferred specification, we construct five groups of industries for electricity and natural gas, based on their electricity and natural gas cost shares. In equation (2) we estimate a separate coefficient for each industry group by including the triple interaction among a set of group fixed effects, the industry cost share, and the energy price. Note that equation (2) includes a full set of cost share-price interactions for the California price and neighboring region price, for both natural gas and electricity. The equation also includes all first- and second-order terms in the triple interactions among the industry group, industry cost share, and energy price, along with interactions of year with industry and census division.

Estimating equation (2) by OLS would yield biased estimates if the energy prices or cost shares are correlated with the error term. For example, a census division experiencing rapid productivity growth could have high electricity or natural gas prices and high output because of the greater regional demand for those fuels. More generally, shocks to factor markets that affect input and output choices could be correlated with electricity or natural gas prices. In equation (2) industry cost shares do not vary over time, and the industry fixed effects control for correlation

[3] The United States contains nine census divisions.

between time-invariant industry-level demand or supply shocks. Time-varying demand and supply shocks should therefore be uncorrelated with the fixed industry cost shares.

Equation (2) would be valid if electricity or natural gas prices are exogenous to such factors. Linn (2008, 2009) argued that this is a valid assumption if division-by-industry-by-year fixed effects are included. In this context that approach is not practical, because much of the electricity or natural gas price variation is at the regional (i.e., utility or state) level.

We can, however, relax the exogeneity assumption by including control variables in X_{ijt}. We include industry-by-year interactions to control for any unobserved demand or supply shocks that proportionately affect all plants in the same industry and year. These interactions also control for competition from other countries, because such competition would depend on relative energy prices between domestic and foreign plants, which vary at the industry-by-year level. Furthermore, we include a labor cost index and control for plant-specific demand shocks using the output of industries that consume products sold by that plant (estimated from input-output tables as discussed below).

Equation (2) describes our short-run model, relating the level of the outcome variables to the levels of energy prices and other control variables, and using annual observations. To examine the long-run impact of energy prices, we relate the *changes* in the outcome variables over a five-year period to the *changes* in energy prices and other control variables over that five-year period. This generates equation (3) below, where *d* refers to five-year changes in the variables. Note that the terms in equation (2) that are fixed over time, including industry fixed effects and industry cost shares, drop out of equation (3) when we use these changes (i.e., take first differences).

$$\begin{aligned} \mathrm{d}\ln(y_{ijt}) &= \beta_0 + \beta_{1e}^E s_j^E d\ln(p_{ijt}^E) + \beta_{2e}^E s_j^E d\ln(p_{R,ijt}^E) + \beta_{1g}^G s_j^G d\ln(p_{ijt}^G) \\ &+ \beta_{2g}^G s_j^G d\ln(p_{R,ijt}^G) + \gamma_{1e}^E \ln d(p_{ijt}^E) + \gamma_{2e}^E \mathrm{dln}(p_{R,ijt}^E) + \gamma_{1g}^G \mathrm{dln}(p_{ijt}^G) + \gamma_{2g}^G \mathrm{dln}(p_{R,ijt}^G) \\ &+ \mu_1 dLCOST_{ijt} + \mu_2 dDGROWTH_{ijt} + \delta_t + \delta_{rt} + \delta_{jt} + \varepsilon_{ijt} \end{aligned} \tag{3}$$

Similar to equation (2), in the baseline estimation of equation (3), we use five cost-share groups for electricity and natural gas, and estimate the equation by OLS.

Data

Dataset Assembly

Both the CMF and ASM include plant-level output and expenditure data from manufacturing plants. The CMF is conducted every five years and includes all manufacturing plants. We use the CMF from 1992, 1997, 2002, and 2007. The ASM samples small plants and includes all large plants, and we use the ASM from 1989 to 2009. Both the ASM and CMF contain plant identifiers that allow us to link observations of the same plant over time.

We first describe the sample construction and then provide details on the variables used for estimation. Beginning with the full ASM and CMF panels, we drop duplicate observations and plants that report non-positive electricity purchased or negative value of shipments.

Next, we restrict the sample to NAICS industries identified by CARB. Because the industry classification system changed from the Standard Industrial Classification (SIC) to NAICS around 1997, we harmonize industry definitions across years. We take a two-step process to impute the NAICS industry code before 1997. First, each plant has a unique identifier, and we sort plants by identifier. When available, we use the plant’s NAICS code from other years to impute the NAICS code prior to 1997 or in the few cases after 1997 where the NAICS code is missing. After the first imputation step, 92 percent of the sample has a NAICS code. In the second step, we construct a SIC-NAICS crosswalk that we use to assign a NAICS code to observations that have a SIC code but a missing NAICS code. For these observations, we can impute the NAICS code only when the SIC code maps into a single NAICS code; for a small number of industries, SIC codes map into multiple NAICS codes. Following this imputation, we eliminate the 2.5 percent of the remaining observations that have missing NAICS codes.

Equations (2) and (3) include the energy prices of plants in other regions. To construct these variables we need to define the set of plants that compete with a particular plant. We define competing plants based on the distance between them, assuming that plants within a certain distance compete with one another. For each plant we determine the sets of states that are located within 250, 500, and 1,000 miles of the plant. Using geocoded census data from the Longitudinal Business Database, we approximate the potential for competition among plants. First, we randomly select 10,000 observations from each state. If at least 1,000 of the businesses in one state are located within 250 miles of 1,000 businesses in another state, those two states are deemed to be within a 250-mile radius of one another. The same calculation is done for the 500- and 1,000-mile distances. The distances of 250, 500, and 1,000 miles were chosen based on an analysis of typical shipping distances from the Commodity Flow Survey (CFS).

Dependent Variables

Output: Total value of shipments, deflated by the price deflator for shipments (PISHIP) provided in the NBER-CES Manufacturing Industry Database.[4]

Value added: Value added as measured in the ASM/CMF (derived by subtracting the cost of materials, supplies, containers, fuel, purchased electricity, and contract work from the value of shipments, adjusting for inventory changes).[5]

Employment: Total employment, including both production and nonproduction workers.

Independent Variables

Electricity cost share: We construct two electricity cost-share measures. The first is the average share of electricity in value of shipments in 1989, analogous to the intensity measures that Aldy and Pizer use. Under the standard assumption that in the long run, plants earn zero economic profits (i.e., accounting for opportunity costs), this share is equal to the cost share. The cost share is assigned to all plants in the same industry. We also construct a plant-level cost share using data from the plant's earliest observation. The plant-level cost share is assigned to the plant's subsequent observations.

Natural gas cost share: The ASM and CMF do not contain natural gas expenditure data. Therefore, we use the 1991 Manufacturing Energy Consumption Survey (MECS), which includes plant-level natural gas expenditure data. Using the MECS, we compute the share of natural gas in total cost (value of shipments) for each industry.

Electricity price: We compute the plant-level electricity price as the ratio of expenditure to quantity purchased. We also compute the quantity-weighted industry average price.

Gas price: Because the ASM and CMF do not contain natural gas expenditure or quantity purchases, we use state-level natural gas prices from the Energy Information Administration.

Neighbor electricity price: The electricity price in neighboring states is the average electricity price across plants in neighboring states, where neighboring states are defined as described above. There are separate neighbor electricity price variables for the 250, 500, and 1000-mile radii. The neighbor prices vary by industry, state, and year.

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4 http://www.nber.org/data/nberces5809.html.

5 http://www.census.gov/manufacturing/asm/definitions/index.html.

Neighbor natural gas price: The natural gas price in neighboring states is constructed similarly to the electricity price, except using the state natural gas prices rather than the plant electricity prices.

Labor cost index: The labor cost index includes average wages from plants in the same industry and state, as well as plants in the same industry in neighboring states. The labor cost index is the ratio of the total payroll to total employment across all such plants, using the 500-mile definition to define the set of neighboring plants, excluding the plant's own payroll and employment.

Demand growth index: The demand growth index for a particular plant measures the demand for that plant's output, based on a complex calculation using multiple data sources, which we describe next.

We begin with input-output (IO) tables from the US Bureau of Economic Analysis (BEA) that identify for every "making" industry how much of its output is purchased by each "using" industry. We use both the 1992[6] (SIC-based) and 2007[7] (NAICS-based) IO tables, and use concordances between the BEA industry codes and the SIC/NAICS industry codes to link the IO tables to each of our plants in each year, identifying which other industries (both manufacturing and nonmanufacturing industries, including final demand) are expected to purchase that plant's products.

We use the 2002 CFS to identify the distances traveled by shipments from plants in each industry, reported by three-digit NAICS industry of the shipped products.[8] For each three-digit NAICS industry, we compute the share of shipments traveling less than 250 miles, the share of shipments traveling between 250 and 1,000 miles, and the share of shipments traveling more than 1,000 miles.

We use annual state-level industry output data from BEA to identify the activity level of different "using" industries around the country.[9] For each plant in our dataset and for each industry that "uses" the products of that plant, we calculate the amount of that industry's production that is located in states within 250 miles of the plant, between 250 and 1,000 miles

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6 http://www.bea.gov/industry/io_benchmark.htm.

7 http://www.bea.gov/industry/io_annual.htm.

8 http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/commodity_flow_survey/index.html.

9 http://www.bea.gov/regional/index.htm.

from the plant, or more than 1,000 miles from the plant. We then use the IO data to predict the demand for the plant's products, aggregated over all these "using" industries, at each of the three distances. We calculate the annual growth rate in product demand at each distance and weight those three growth rates using the CFS weights for the share of the plant's shipments expected to travel those distances, yielding a weighted projected demand growth. Finally, we transform these growth rates into an index number by assigning them all a value of 150 in 1987.[10]

County fuel mix: The county fuel mix is the share of natural gas in total production by those utilities distributing electricity in the county. We obtain electricity generation data from the Environmental Protection Agency's eGrid database,[11] including only utility-operated plants (i.e., excluding generating units at manufacturing plants). For each utility, we compute total annual electricity generation and generation by fuel type, focusing on the share generated by natural gas. The county-level share of natural gas in generation is the generation-weighted average of the natural gas share across utilities in the county. The utilities operating in each county are identified using Energy Information Administration data that specify in which counties each individual utility maintains the equipment necessary for electricity distribution.[12] Prior to 1999 the necessary data are not available, and we use the natural gas share from the first available year for each county. When the necessary data are missing for a county after 1999, the natural gas share is linearly interpolated from the available years for that county.

Industry energy groups: We have allowed for differences among groups of industries in our estimation models, based on the intensity of their use of electricity and natural gas. Our main regressions assign industries to five groups, but we also examined other models with up to 10 groups, as well as models that combine all industries into one group. We use the industry-level electricity cost shares taken from published ASM data to assign industries to electricity groups. We use the 1991 Manufacturing Energy Cost Survey data to calculate natural gas cost shares for each industry, and then use those cost shares to define the cutoff values for assigning industries to groups.

[10] The starting value of 150 in 1987 was chosen so that the demand index numbers would remain positive throughout the sample for all industries.

[11] http://www.epa.gov/cleanenergy/energy-resources/egrid/.

[12] http://www.eia.gov/electricity/data/eia861/.

Short- and Long-Run Estimation

This section presents the parameter estimates from the baseline short- and long-run models. Table 1 displays the industries included in the analysis. We use different samples and estimation models for the short and long runs. The short-run sample includes all observations from 1989 through 2009. Besides the energy prices and interaction terms for the plant and plants in neighboring areas, the short-run model includes fixed effects for industry, year, division-year, and industry-year, as well as the labor cost index and the demand growth index. The long-run models are estimated using only the data from the CMF years, which include data for all plants.[13] As noted earlier, the long-run model omits those variables that do not vary over time and translates all continuous (non-dummy) variables into changes over the five-year period; otherwise the basic structure of the model remains the same between the short-run and long-run analyses.

We must make several choices about the variable construction when estimating the short- and long-run equations (2) or (3), respectively. First, we need to choose the number of electricity and natural gas groups. We have tried estimating the model with one through ten groups, and in this section we focus on the estimates using five groups. The five groups appear to sufficiently capture the cross-industry heterogeneity; below we compare the five-group results with those using one or three groups.

Second, we choose between using the plant's electricity cost share and the industry's electricity cost share. Using the plant's cost share would reduce measurement error because of within-industry variation in cost shares, but if the plant's cost share is correlated with unobserved plant characteristics, the coefficient estimates would be biased. Balancing these considerations, we focus on the results using industry-level electricity cost shares, but we also show some results using plant-level cost shares. Note that we do not have plant-specific cost shares for natural gas, and all our results use industry-level cost shares for natural gas.

Third, we must define the set of plants that compete with a California plant. Based on observed distance of shipments, we include plants within a 500-mile radius as competitors, but we also show results using a 250-mile radius.

[13] Note that the short-run and long-run analyses are based on different samples of data. In particular, the short-run analysis is based on a larger sample of data, since it includes observations from the ASM years between CMF years. However, our short-run results did not change substantially when we restricted that analysis to the sample of observations used in the long-run analysis.

Some of the industries in the analysis did not have sufficient numbers of observations to release their results individually because of Census disclosure avoidance rules. For these industries, we aggregated the results for several industries together (with the bundling based on the industries' energy cost share). This bundling is shown in Table 1. The short-run sample includes more observations, and we create two bundles (S1 and S2) that collectively include the 7 industries for which we cannot disclose individual short-run results due to Census confidentiality disclosure restrictions. The smaller sample size for the long-run analysis required us to collect 15 industries into three bundles (L1, L2, and L3). For all bundled industries, we report the bundle-wide mean results.

We present the results of the main estimation models for equation (2), for the short and equation (3) for the long run. The sample size, across all industries, is about 170,000 observations for the short-run estimation and 36,000 for the long-run estimation. Because there are so many parameters in the model, it is difficult to interpret the estimates of individual parameters. We summarize the key results by reporting the elasticities of employment, output, and value added with respect to electricity and natural gas prices that the plant faces in Tables 2 (short run) and 3 (long run). For reference, the tables also report cost shares, which are the percentage of energy in total costs.[14]

These tables reveal some clear patterns. As expected, most cost shares for both electricity and natural gas are less than 1 percent, although seven industries have natural gas shares exceeding 5 percent: paperboard mills, industrial gas manufacturing, nitrogenous fertilizer manufacturing, flat glass manufacturing, glass container manufacturing, lime manufacturing, and mineral wool manufacturing. The highest electricity cost share is 2.64 percent (mineral wool manufacturing).

As discussed above, we expect the energy prices the plant faces to negatively affect its employment, output, and value added. With few exceptions, almost all the short-run elasticities have negative signs, and most are statistically significant at the 5 percent level. The elasticities are highly correlated across outcomes; industries with relatively large (negative) elasticities with respect to one outcome tend to have large (negative) elasticities with respect to other outcomes. At the same time, we observe several cases where the signs are positive for one or more of the

[14] For Census confidentiality reasons, the electricity and natural gas cost shares used in this table and Figures 1 and 2, as well as the overall energy cost shares used in Figures 3 and 4, are taken from published industry-level data and are not the ones used in the estimation process (though they should be quite similar to one another).

outcome measures. In only three industries (setup paperboard box manufacturing, biologic product [except diagnostic] manufacturing, and all other motor vehicle parts manufacturing) are the elasticities positive and statistically different from zero for all three outcome measures, and that is only with natural gas. In all those cases, the natural gas cost share is 1.2 percent or less. Across industries, the average short-run electricity price elasticities are –0.8 for output, –0.6 percent for employment, and –0.8 percent for value added (e.g., for a 1 percent increase in short-run electricity prices, the average short-run response is an 0.8 percent drop in output, a 0.6 percent drop in employment, and an 0.8 percent drop in value added.) The magnitudes of the natural gas price elasticities are smaller than the electricity elasticities: –0.1 for output, 0.01 for employment, and –0.01 for natural gas. Our elasticity estimates are roughly consistent with those reported by Kahn and Mansur (2013), and slightly larger than the Aldy and Pizer (2015) estimates, which may reflect our narrower plant-level boundaries and control for energy prices in other states vs. their national-level framework.

Turning to the long-run results (Table 3), we observe generally similar patterns. There are more positive values than for the short run, albeit mostly not statistically significantly different from zero. The negative elasticities tend to be somewhat smaller (less negative) in the long run than the short run. Across industries, the average elasticities are negative but are much smaller than the short-run elasticities at less than 0.1 in magnitude. Economic theory suggests that the elasticity of output to energy prices should approximately equal the cost share of energy. Given an average electricity cost share of 0.01 and natural gas cost share of 0.02, the typical long-run elasticities in Table 3 are consistent with theory, including for the most energy-intensive industries in our sample (flat glass and industrial gases).

Table 4 displays the correlations between the electricity and gas cost shares and the elasticities for the different outcomes.[15] As expected, all the cost shares are negatively correlated with the outcomes. That is, the greater the cost share, the greater the (negative) value of the elasticity. Across outcomes the elasticities tend to be highly correlated with one another, meaning that industries that experience large employment effects also experience large output and value-added effects. This correlation across outcomes is consistent with expectations.

Figures 1 and 2 show the relationships between the cost shares and elasticities. Estimated elasticities tend to be more dispersed for industries that have relatively low-cost shares than for

[15] These are Spearman rank order correlations to reduce the influence of outliers.

other industries, and nearly all of the (unexpected) positive elasticities are concentrated in the low-cost share industries. This variation, combined with statistical uncertainty, suggests some overall uncertainty in the short-run responses to energy prices for industries with very low energy cost shares. Overall, the highest cost-share industries tend to have higher elasticities (in magnitude) than the smaller cost-share industries, which suggests that energy price changes have larger (more negative) effects on the more energy intensive industries. This result is consistent with expectations and supports the validity of the modeling approach.

Simulations

This section describes how we use the estimated coefficients from our main statistical analysis to simulate the short- and long-run effects of imposing a GHG compliance cost on California plants in the estimation sample. Equation (2) characterizes the short-run effects of a plant's energy prices and the energy prices in other regions on its output, value added, and employment, and equation (3) characterizes the long-run effects. Importantly for the simulations, the regressions include year-fixed effects, which hold fixed national output, value added, and employment. Therefore, in the simulations, we hold these outcomes fixed at their actual levels in 2009. That is, the simulations allow us to characterize the extent to which a GHG compliance cost only on California plants may cause manufacturing activity to shift from California to other states, under the assumption that national activity is unaffected.

To approximate the effects of California's Cap-and-Trade Program, we increase the electricity and natural gas prices in California from their observed values in 2009, which is the last year of the sample. Specifically, we assume a compliance cost of $10/metric ton CO_2, which translates to an electricity price increase of $0.005525/ kilowatt hour (assuming the price increase is proportional to the emissions rate of a gas-fired generator) and a natural gas price increase of $0.545/thousand cubic feet. These price changes, which assume that compliance costs are fully passed through to end users, represent increases of 4.2 percent in electricity prices and 8.6 percent in natural gas prices. For non-California plants, their own electricity and natural gas prices are held constant at their actual 2009 levels.

We calculate "counterfactual" predicted values for output, value added, and employment for each plant, using equations (2) and (3) and these new values for electricity and natural gas prices. We compare these predicted values, plant by plant, with the "actual" predicted values obtained when we using the original 2009 prices. In the counterfactual case, California plants experience a change in their own energy prices; non-California plants experience a change in their neighboring prices if they are close enough to California. We then calculate the aggregate change for each outcome for all California plants by industry, and similarly for all non-California plants by industry. Because we assume that the aggregate nationwide value is held fixed, we rescale the California and non-California values to ensure that the total level of national activity in each industry remains the same in the actual and counterfactual scenarios (i.e., the decreases at California plants are exactly offset by the increases in non-California plants). This approach is consistent with our statistical models, which effectively hold fixed national outcomes and characterizes the effects of energy prices on an individual plant's activity relative to plants located in other regions. The leakage estimates therefore correspond to the relative changes between California and other regions, and do not reflect absolute levels. For example, if a California Cap-and-Trade Program compliance cost were to reduce national totals by decreasing consumption or increasing imports, the reductions in California would be larger in absolute terms than those reported here, and the increases outside of California would be smaller in absolute terms.

Simulation Results

Short Run

Table 5 displays the short-run effects of hypothetical Cap and Trade-Program-based energy price increases on output, employment, and value added. As discussed above, to approximate California's Cap and-Trade Program, we simulate the effects of a \$10/metric ton CO_2 compliance cost on top of California's 2009 energy prices. The energy prices of plants in other states are not affected, and by assumption the energy price changes cause a shift of economic activity within the United States but do not affect national totals. Note that non-CO_2 greenhouse gases emitted during the manufacturing process ('process emissions'), which were not included in the statistical model, are also absent from the simulations. Thus, we implicitly assume a zero compliance cost for process emissions, which clearly understates the impacts for nitrogenous fertilizer manufacturing (NAICS 325311), industrial gas manufacturing (NAICS 325120), lime manufacturing (NAICS 327410), secondary smelting, refining and alloying of nonferrous metals (NAICS 331492) and other industries emitting non-CO_2 greenhouse gases in significant quantities.

The results in Table 5 are arrayed from largest to smallest output effects. Focusing on the first column (output), we see the largest losses in glass container manufacturing (17 percent), paperboard mills (14 percent), automobiles (13 percent), iron and steel mills and ferroalloy manufacturing (12 percent), and poultry processing (11 percent). The next five industries, also ranked on the basis of estimated output losses, have output effects close to 10 percent: mineral wool manufacturing, ethanol, flat glass manufacturing, lime manufacturing, and iron foundries. Across industries, output declines by 5.7 percent on average.

For employment and value added, the rankings are quite similar, albeit not identical. The impacts are generally smaller than the impacts on output, especially for employment losses. Note that for all three outcomes there are a few positive effects, which mirror the positive values estimated for the elasticities, as shown in Tables 2 and 3. In most cases, these elasticities were not statistically different from zero, and the corresponding cost shares were small. Across industries, employment falls by 3.7 percent on average, and value added falls by 5.1 percent on average.

We present supplemental calculations of the reductions in short-run value added based on an assumed compliance cost of \$22.62/metric ton CO_2. We also consider the effects of hypothetical rebates of 10 to 90 percent of the compliance cost. The corresponding electricity and natural gas prices used in these simulations are extrapolations of the \$10/ton CO_2 compliance cost case. The \$22.62/metric ton CO_2 compliance cost translates to an electricity price increase of \$0.001250 / kilowatt hour and a natural gas price increase of \$1.232/ thousand cubic feet. The resulting value-add losses, displayed in appendix table A1, are larger than those shown for the \$10/metric ton CO_2 compliance cost case shown in table 5, varying approximately on a linear basis.

Long Run

Table 6 displays the long-run impacts on the various outcome metrics. As shown, the long-run losses for all three metrics—output, employment, and value added—are uniformly smaller than the short-run estimates. This suggests that plants can adapt to an energy price shock. For example, they may adopt energy-efficient technology. The largest long-run output losses are less than 1 percent, and most industries have impacts very close to zero. The average effects are a 0.2 percent increase for output, a 1.3 percent decrease for employment, and a 0.1 percent decrease for value added. These changes are roughly consistent with the changes predicted by a Cobb-Douglas production function, for which the elasticity of output to energy prices is equal to the share of energy in total costs (mathematically, a Cobb-Douglas production function represents an approximation to a more complicated production function).

In Table 7, we observe negative correlations between the short- and long-run effects. Although one might expect to observe a high positive correlation, in fact there is not a theoretical reason why there should be one. The relatively energy-intensive industries have larger short-run responses, as we showed above. But those industries are also more likely to adopt energy-saving technology because of greater savings that such technology would offer. Technology adoption concentrated in energy-intensive industries would reduce the correlation between the short- and long-run effects, compared with a situation in which all industries are equally likely to adopt technology—though the negative correlations are still surprising.

We also find some positive long-run responses, most notably for the bundle of five low-energy-cost industries (L1), which contradicts our theory-based expectations. That bundle of industries also shows a negative impact on employment and value added, which contrasts with their positive impact on output. These results raise the possibility that there could be too little variation in energy prices faced by a plant over time to identify the impacts accurately. It could also be because long-run responses are more difficult to model, and our model may be too simple to capture the long-run responses for certain industries. Although the estimates for a typical industry are consistent with theory, the industry-specific results suggest caution with using the long-run results for individual industries.

Figure 3 graphs the simulated impacts against the overall energy cost share of the different industries. As we saw with the elasticities (in Figures 1 and 2), the industries with low cost shares tend to have more dispersion in their values. The comparison of the results in Figure 3 also points out the dramatic difference between our short-run and long-run results, in terms of the estimated magnitudes, with the long-run impacts in Figure 3 being for the most part clustered closer to zero.

Sensitivity Analysis

The results discussed above all refer to our baseline model, which allows the energy price coefficients to vary across five industry groups, uses industry-level cost shares for both electricity and natural gas, and defines neighboring plants as those within 500 miles. We estimated models that differ from the baseline along all of these dimensions, using three and one industry groups, the plant-level vs industry-level cost share for electricity, and neighboring plants within 250 miles. We also explored using a weighted regression, giving more weight to plants with larger values of the outcome variable.

Table 8 shows the distribution of the estimated impacts of the simulated energy price increase on output, employment, and value added, for both our short-run and long-run models. The right-hand column summarizes the distribution of impacts for a given model. The 49 industry impacts for the model were sorted, from most negative to most positive, and three averages were calculated. The H value is the average of impact values 3–7, among the most negative impacts. The M value is the average of impact values 13–37, the central tendency of the impacts. The L value is the average of impact values 43–47, among the smallest negative (or most positive) impacts. The values range from –12 percent to +12 percent, with zero being represented by Z (in the middle of the graph, not shown when one of the letters falls in that position) and each dot representing 0.5 percentage points. When more than one letter appears in the same position, an X is shown (no ambiguity arises, since the letters always appear in the order H-M-L; e.g., the X for the long-run output impact for three groups, industry cost shares, 500-mile neighbors, unweighted model represents both H and M).

The distribution of impacts, and the relationship across different models, is quite similar for the short-run models. In almost all cases, the impacts are negative, with somewhat smaller impacts on employment than on output or value added. Models using fewer groups have less variation in impacts across industries, as do models using plant-level electricity cost shares. Using a 250-mile definition for neighboring plants or weighting the models by plant size has little impact on the distribution of impacts.

The distribution of impacts is quite different for the long-run models. Most obviously, the estimated impacts are in most cases very close to zero, especially for impacts on output, and positive impacts are more common. A few of the value-added models show substantial dispersion, and this dispersion is larger for the 1-group and the weighted model than it is from the base model.

Tables 9 and 10 show the correlations of the estimated elasticities to electricity and natural gas prices, across alternative versions of equations (2) and (3). The three panels show correlations for output, employment, and value added. Across models, we vary the number of groups (one, three, or five), whether we use 250 or 500 miles to define competing plants, and whether or not we weight observations. Tables 11 and 12 show similar correlations for the simulated percentage changes in the outcomes caused by energy price increases.

For the most part, the results are very highly correlated across the different variations of the models, especially for the short-run models. The results appear to be particularly insensitive to the distance used to define competing plants. The correlations between the 500-mile and 250-mile definitions of neighbors are quite high, ranging between 0.8 and 0.99.

The long-run analysis characterizes the effects of energy prices on employment, output, and value added at plants in our sample that continue operating more than 5 years. An increase in energy prices could also cause some plants to exit in the long run. To consider this possibility, we have conducted an analysis of plant exit using a linear probability model based on equation (3). The analysis uses the CMF dataset, which provides data on all manufacturing plants every five years. We define an exit as a plant that is operating in one CMF year (1992, 1997, or 2002) and does not appear in any subsequent CMF (through 2007).

Because the data sample used in the exit analysis (consisting of about 50,000 plants) overlaps with those used for the short-run and long-run analyses, but is not identical to either of them, Census Bureau disclosure avoidance rules preclude our releasing quantitative results from the exit analysis. Consequently, we describe the results qualitatively.

We use the estimated coefficients from the exit regression to calculate the predicted number of plant exits among California plants in each industry, given the baseline 2009 values for electricity and natural gas prices. Consistent with our other simulations, we then increase those energy prices and recalculate the number of exits. For our baseline model (5 industry groups, industry electricity cost-shares, and 500-mile neighbors), the energy price increase raises plant exit in about 30 industries and reduces exit in the other 20. The magnitude of the exit changes are quite small: the average industry has about 0.5 additional plants exiting California with the higher energy prices, and only a few industries have more than 1 additional plant predicted to exit. Translated into percentage effects, the predicted impact of exit on reducing output, employment, or value added is less than 1 percent for all except a handful of industries, and is never more than about 3 percent. The exit effects are weakly correlated across industries with the short-run employment, output, and value-added impacts described earlier, with correlations of about -0.1 (i.e., industries predicted to have larger output declines are also predicted to have slightly more exit). Finally, the elasticity of the exit rate with respect to the energy prices has the expected positive sign for electricity prices in most cases, but the exit elasticity with respect to natural gas prices is often negative.

Conclusions

California regulators face a challenge in estimating the impacts of California's Cap-and-Trade Program on the state's EITE industries. California's Cap-and-Trade Program is expected to affect the state's energy prices relative to prices in other regions. Analyzing historical effects of energy prices on economic activity inside and outside California, with particular focus on differences in energy prices between California and nearby regions, is one way to model the potential impacts. We have developed a statistical model and used such an approach, focusing on the industrial sectors that are covered by California's Cap-and-Trade Program. Several conclusions can be drawn from this analysis:

1. *An increase in California energy prices relative to prices in nearby regions will raise production costs in energy-intensive industries located in California and likely result in short-term (one year) losses in output, employment, and value added for those industries*. For an assumed compliance cost of $10/metric ton of CO_2, the largest losses are estimated in glass container manufacturing (17 percent), paperboard mills (14 percent), automobiles (13 percent), iron and steel mills and ferroalloy manufacturing (12 percent), and poultry processing (11 percent). Another group of five industries has estimated losses of about 10 percent, while losses in all industries average about 5.7 percent. A few industries show no statistically significant indication of losses, e.g., wineries. The typical industry experiences short-run employment, output, and value-added decreases of 4–6 percent. For higher assumed compliance costs (up to $22.62/metric ton of CO_2), losses are larger, approximately on a linear basis.
2. *We estimate smaller effects for the long run than the short run, although we offer caution when interpreting these long-run results*. The results suggest that increases in California energy prices have much smaller effects over a five-year time period than over a one-year time period. The typical industry experiences a long-run output increase of 0.2 percent and employment and value-added decreases of 1.3 and 0.1 percent. The largest output losses after five years are below 1 percent, with most industries experiencing much smaller impacts. For a number of industries in the long-run analysis, we estimate positive although usually small effects of energy prices on employment, output, or value added. We suggest two explanations for this seemingly anomalous long-run result. First, the lack of statistical significance for many of the long-run estimates suggests that there may not be sufficient historical energy price variation to estimate the effects. Second, the long-run responses are inherently more complicated to model than the short-run responses, because the long run includes dynamic decisions about investment and plant closure. While a benefit of our approach is its relative simplicity and transparency in modeling the effects of energy prices on economic activity, we may not suitably capture some of the nuances for certain industries, particularly in the long run. Therefore, we caution against focusing on the long-run estimates for individual industries and instead highlight the overall finding that, across the wide range of statistical models we have estimated, the effects

of energy prices on employment, output, and value added for a typical industry seem to be much smaller in the long run than in the short run.

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Tables and Figures

See following pages.

Table 1. Industries Included in Analysis

Industry Name	NAICS	Short-run bundles	Long-run bundles
Breakfast Cereal Manufacturing	311230	S1	L1
Sugar manufacturing (311311-311313)	311310		L2
Fruit and Vegetable Canning	311421		
Dried and Dehydrated Food Manufacturing	311423		
Creamy Butter Manufacturing	311512	S1	L1
Cheese Manufacturing	311513		
Dry, Condensed, and Evaporated Dairy Product Manufacturing	311514		
Animal (except Poultry) Slaughtering	311611		
Rendering and Meat Byproduct Processing	311613		
Poultry Processing	311615		
Roasted Nuts and Peanut Butter Manufacturing	311911		
Other Snack Food Manufacturing	311919		L2
Perishable Prepared Food	311991		
All Other Miscellaneous Food Manufacturing	311999		
Breweries	312120	S1	L2
Wineries	312130		
Paper (except Newsprint) Mills	322121		
Paperboard Mills	322130		
Setup Paperboard Box Manufacturing	322213		L2
Petroleum Refineries	324110		
Asphalt	324121		
Other Petroleum Products	324199		L2
Industrial Gas Manufacturing	325120		
All Other Basic Inorganic Chemical Manufacturing	325188		
Ethanol	325193	S2	L3
All Other Basic Organic Chemical Manufacturing	325199		
Nitrogenous Fertilizer Manufacturing	325311		
Pharmaceutical Preparation Manufacturing	325412		

Table 1 (continued).

Industry Name	NAICS	Short-run bundles	Long-run bundles
Biological Product (except Diagnostic) Manufacturing	325414		
Flat Glass Manufacturing	327211	S2	L3
Glass Container Manufacturing	327213		L3
Cement Manufacturing	327310		
Lime Manufacturing	327410	S2	L3
Gypsum Product Manufacturing	327420		
Mineral Wool Manufacturing	327993		
Iron and Steel Mills and Ferroalloy Manufacturing	331111		
Rolled Steel	331221		L2
Secondary Smelting and Alloying of Aluminum	331314		
Aluminum Extruded Product Manufacturing	331316		
Secondary Smelting/Refining/Alloying of Nonferrous Metal	331492		
Iron Foundries	331511		
Forging and Stamping	332111		
Nonferrous Forging	332112		
Hardware	332510		
Turbine and Turbine Generator Set Units Manufacturing	333611	S1	L1
Automobiles	336111		L1
All Other Motor Vehicle Parts Manufacturing	336399		
Aircraft Manufacturing	336411		
Missiles	336414		L1

Notes : Wet Corn Milling, NAICS 311221, was dropped entirely due to technical issues. Bundles allow us to release average results of industries in cases where we could not release the individual industry-level results. Industries with a common bundle identifier are assigned to the same bundle for the short-run (S) or long-run (L) analysis.

Table 2a. Short-Run Elasticities with Respect to Electricity Prices

Industry Name	NAICS	Electricity Cost Share	Output	Employment	Value Added
Breakfast Cereal	311230 (S1)	0.27	-1.09*	-0.76*	-1.05*
Sugar	311310	0.36	-0.16*	-0.17*	-0.04
Fruit and Veg	311421	0.50	0.23*	0.16*	0.08
Dried and Dehydrated Food	311423	0.50	-0.04	-0.12*	-0.06*
Creamy Butter	311512 (S1)	0.43	-1.09*	-0.76*	-1.05*
Cheese	311513	0.40	-0.66*	-0.45*	-0.58*
Dairy Product	311514	0.64	-0.36*	-0.22*	-0.32*
Slaughtering	311611	0.42	0.03	-0.06	0.17*
Meat Processing	311613	0.43	-0.80*	-0.68*	-0.84*
Poultry Processing	311615	0.52	-0.81*	-0.62*	-0.70*
Nuts and Peanut Butter	311911	0.32	-1.10*	-0.70*	-1.05*
Other Snack Food	311919	0.32	-1.08*	-0.69*	-1.03*
Perishable Prepared Food	311991	0.39	-0.46*	-0.25*	-0.40*
All Other Misc. Food	311999	0.39	-0.52*	-0.27*	-0.44*
Breweries	312120 (S1)	0.64	-1.09*	-0.76*	-1.05*
Wineries	312130	0.29	-0.28*	-0.24*	-0.16*
Paper Mills	322121	1.32	-0.79*	-0.70*	-0.90*
Paperboard Mills	322130	2.35	-1.40*	-1.07*	-1.42*
Setup Paperboard Box	322213	0.38	-0.51*	-0.27*	-0.44*
Petroleum Refineries	324110	0.25	-0.54*	-0.28*	-0.46*
Asphalt	324121	0.32	0.20*	-0.04	0.14*
Other Petroleum Products	324199	0.00	-0.81*	-0.66*	-0.79*
Industrial Gas	325120	5.56	-0.56*	-0.17*	-0.63*
All Other Basic Inorg. Chem.	325188	3.35	-0.79*	-0.71*	-0.91*
Ethanol	325193 (S2)	0.49	-1.11*	-0.85*	-1.16*
All Other Basic Org. Chem.	325199	0.19	-0.81*	-0.66*	-0.79*
Nitrogenous Fertilizer	325311	0.21	-1.35*	-1.02*	-1.37*
Pharmaceutical Preparation	325412	0.20	-0.54*	-0.42*	-0.50*

Table 2a (continued).

Industry Name	NAICS	Electricity Cost Share	Output	Employment	Value Added
Biological Product	325414	0.35	-0.48*	-0.26*	-0.42*
Flat Glass	327211 (S2)	2.07	-1.11*	-0.85*	-1.16*
Glass Container	327213	2.45	-1.42*	-1.10*	-1.44*
Cement	327310	3.01	-1.19*	-0.85*	-1.22*
Lime	327410 (S2)	1.18	-1.11*	-0.85*	-1.16*
Gypsum Product	327420	1.37	-0.80*	-0.70*	-0.87*
Mineral Wool	327993	2.64	-1.42*	-1.10*	-1.45*
Iron and Steel Mills and Ferroalloy	331111	1.03	-1.42*	-1.09*	-1.44*
Rolled Steel	331221	1.14	-0.17*	-0.16*	-0.16*
Secondary Aluminum Smelt/Alloying	331314	2.49	-0.79*	-0.71*	-0.90*
Aluminum Extruded Product	331316	0.88	-0.81*	-0.67*	-0.80*
Secondary Nonferrous Metal Proc.	331492	0.85	-0.81*	-0.68*	-0.83*
Iron Foundries	331511	2.17	-1.38*	-1.05*	-1.40*
Forging and Stamping	332111	1.65	-0.79*	-0.71*	-0.90*
Nonferrous Forging	332112	1.65	-0.80*	-0.69*	-0.86*
Hardware	332510	0.49	-0.05	-0.04	-0.13*
Turbines	333611 (S1)	0.38	-1.09*	-0.76*	-1.05*
Automobiles	336111	0.22	-1.83*	-1.11*	-1.84*
All Other Motor Vehicle Parts	336399	0.57	-0.76*	-0.59*	-0.66*
Aircraft	336411	0.18	-0.22*	-0.18*	-0.26*
Missiles	336414	0.31	-0.13*	-0.15*	-0.00
Average		0.99	-0.75	-0.57	-0.75

Notes : The table reports the estimated elasticity of the outcome indicated in the column heading with respect to electricity. For example, an elasticity of one implies that a 1 percent increase in the electricity price causes a 1 percent increase in the outcome. Elasticities are computed after estimating equation (2) using the baseline specification (5 cost-share groups, industry cost shares, and 500 miles). For industries in the same bundle a common elasticity is reported. Cost share is the percentage of electricity in total costs, computed from published industry-level data. The bottom of the table reports the average elasticity across industries.

Table 2b. Short-Run Elasticities with Respect to Natural Gas Prices

Industry Name	NAICS	Natural Gas Cost Share	Output	Employment	Value Added
Breakfast Cereal	311230 (S1)	0.60	-0.11	-0.02	-0.02
Sugar	311310	1.34	-0.13*	0.01	-0.13
Fruit and Veg	311421	1.61	-0.49*	-0.43*	-0.07
Dried and Dehydrated Food	311423	1.61	-0.31*	-0.27*	-0.22*
Creamy Butter	311512 (S1)	0.88	-0.11	-0.02	-0.02
Cheese	311513	0.81	0.60*	0.52*	0.60*
Dairy Product	311514	1.29	-0.17*	0.01	-0.12
Slaughtering	311611	0.78	-0.27*	-0.16*	-0.21*
Meat Processing	311613	0.78	-0.30*	-0.26*	-0.20*
Poultry Processing	311615	0.95	-0.49*	-0.50*	-0.52*
Nuts and Peanut Butter	311911	0.72	-0.22*	-0.06	-0.13
Other Snack Food	311919	0.72	0.61*	0.52*	0.61*
Perishable Prepared Food	311991	0.88	0.02	0.13	-0.12
All Other Misc. Food	311999	0.88	-0.31*	-0.24*	-0.09
Breweries	312120 (S1)	0.86	-0.11	-0.02	-0.02
Wineries	312130	0.40	1.00*	0.82*	0.91*
Paper Mills	322121	3.67	-0.14*	0.01	-0.13
Paperboard Mills	322130	5.78	-0.31*	-0.26*	-0.21*
Setup Paperboard Box	322213	0.74	0.61*	0.52*	0.60*
Petroleum Refineries	324110	1.42	-0.29*	-0.21*	-0.09
Asphalt	324121	3.11	-0.31*	-0.27*	-0.21*
Other Petroleum Products	324199	0.08	-0.03	0.08	-0.12
Industrial Gas	325120	10.62	-0.31*	-0.27*	-0.21*
All Other Basic Inorg. Chem.	325188	2.55	-0.18*	0.01	-0.11
Ethanol	325193 (S2)	4.98	-0.30*	-0.25*	-0.19*
All Other Basic Org. Chem.	325199	2.67	-0.27*	0.02	-0.08
Nitrogenous Fertilizer	325311	6.15	-0.13	0.04	0.25
Pharmaceutical Preparation	325412	0.26	-0.24*	-0.10	-0.16

Table 2b (continued).

Industry Name	NAICS	Natural Gas Cost Share	Output	Employment	Value Added
Biological Product	325414	0.55	0.62*	0.53*	0.61*
Flat Glass	327211 (S2)	14.82	-0.30*	-0.25*	-0.19*
Glass Container	327213	9.38	-0.31*	-0.27*	-0.22*
Cement	327310	1.26	0.00	-0.00	-0.19
Lime	327410 (S2)	0.71	-0.30*	-0.25*	-0.19*
Gypsum Product	327420	10.69	-0.28*	-0.22*	-0.14
Mineral Wool	327993	5.29	-0.07	0.00	-0.16
Iron and Steel Mills and Ferroalloy	331111	2.06	-0.20*	0.01	-0.11
Rolled Steel	331221	1.20	1.06*	0.87*	0.96*
Secondary Aluminum Smelt/Alloying	331314	3.88	-0.09	0.00	-0.15
Aluminum Extruded Product	331316	2.10	-0.07	0.04	-0.11
Secondary Nonferrous Metal Proc.	331492	0.98	0.20	0.33*	-0.14
Iron Foundries	331511	1.60	-0.19*	-0.10	-0.10
Forging and Stamping	332111	2.12	-0.23*	0.01	-0.10
Nonferrous Forging	332112	2.12	-0.24*	0.02	-0.09
Hardware	332510	0.63	-0.09	-0.01	0.05
Turbines	333611 (S1)	0.39	-0.11	-0.02	-0.02
Automobiles	336111	0.32	-0.15	0.05	-0.03
All Other Motor Vehicle Parts	336399	0.56	0.16*	0.18*	0.25*
Aircraft	336411	0.20	-0.23*	-0.08	-0.14
Missiles	336414	0.29	-0.08	0.16	0.07
Average		2.41	-0.07	0.01	-0.01

Notes : The table is constructed similarly to Table 2a except reporting natural gas cost shares rather than electricity cost shares and elasticities with respect to natural gas prices rather than electricity prices.

Table 3a. Long-Run Elasticities with Respect to Electricity Prices

Industry Name	NAICS	Electricity Cost Share	Output	Employment	Value Added
Breakfast Cereal	311230 (L1)	0.27	-0.11*	0.01	-0.14
Sugar	311310 (L2)	0.36	-0.02	0.02	-0.04
Fruit and Veg	311421	0.50	-0.02	0.01	-0.12
Dried and Dehydrated Food	311423	0.50	-0.06	0.12	-0.31
Creamy Butter	311512 (L1)	0.43	-0.11*	0.01	-0.14
Cheese	311513	0.40	-0.05	0.03	-0.05
Dairy Product	311514	0.64	0.05	0.07*	0.02
Slaughtering	311611	0.42	0.09*	0.09*	0.15*
Meat Processing	311613	0.43	-0.04	-0.02	-0.10*
Poultry Processing	311615	0.52	0.13*	0.04	0.24*
Nuts and Peanut Butter	311911	0.32	-0.14*	-0.01	-0.19
Other Snack Food	311919 (L2)	0.32	-0.02	0.02	-0.04
Perishable Prepared Food	311991	0.39	0.09*	0.05*	0.13*
All Other Misc. Food	311999	0.39	0.11*	0.04	0.19*
Breweries	312120 (L2)	0.64	-0.02	0.02	-0.04
Wineries	312130	0.29	0.03	0.06*	0.06
Paper Mills	322121	1.32	-0.15*	-0.03	-0.25*
Paperboard Mills	322130	2.35	-0.17*	-0.05*	-0.17*
Setup Paperboard Box	322213 (L2)	0.38	-0.02	0.02	-0.04
Petroleum Refineries	324110	0.25	0.12*	0.04	0.22*
Asphalt	324121	0.32	0.07*	-0.01	0.05
Other Petroleum Products	324199 (L2)	0.00	-0.02	0.02	-0.04
Industrial Gas	325120	5.56	-0.13	-0.08	0.00
All Other Basic Inorg. Chem.	325188	3.35	-0.17*	-0.05*	-0.18*
Ethanol	325193 (L3)	0.49	-0.15*	-0.05*	-0.16*
All Other Basic Org. Chem.	325199	0.19	0.06*	-0.01	0.04
Nitrogenous Fertilizer	325311	0.21	-0.17*	-0.06*	-0.16*
Pharmaceutical Preparation	325412	0.20	-0.02	0.06*	-0.02

Table 3a (continued).

Industry Name	NAICS	Electricity Cost Share	Output	Employment	Value added
Biological Product	325414	0.35	0.10*	0.05*	0.16*
Flat Glass	327211 (L3)	2.07	-0.15*	-0.05*	-0.16*
Glass Container	327213 (L3)	2.45	-0.15*	-0.05*	-0.16*
Cement	327310	3.01	-0.16*	-0.06*	-0.13*
Lime	327410 (L3)	1.18	-0.15*	-0.05*	-0.16*
Gypsum Product	327420	1.37	-0.10*	-0.02	-0.19*
Mineral Wool	327993	2.64	-0.17*	-0.05*	-0.18*
Iron and Steel Mills and Ferroalloy	331111	1.03	-0.17*	-0.05*	-0.18*
Rolled Steel	331221 (L2)	1.14	-0.02	0.02	-0.04
Secondary Aluminum Smelt/Alloying	331314	2.49	-0.15*	-0.03	-0.25*
Aluminum Extruded Product	331316	0.88	0.04	-0.01	0.01
Secondary Nonferrous Metal Proc.	331492	0.85	-0.02	-0.02	-0.07
Iron Foundries	331511	2.17	-0.17*	-0.05*	-0.17*
Forging and Stamping	332111	1.65	-0.15*	-0.03	-0.26*
Nonferrous Forging	332112	1.65	-0.08*	-0.02	-0.16*
Hardware	332510	0.49	-0.02	0.03	-0.09
Turbines	333611 (L1)	0.38	-0.11*	0.01	-0.14
Automobiles	336111 (L1)	0.22	-0.11*	0.01	-0.14
All Other Motor Vehicle Parts	336399	0.57	-0.02	0.08*	0.01
Aircraft	336411	0.18	-0.02	0.04	-0.06
Missiles	336414 (L1)	0.31	-0.11*	0.01	-0.14
Average		0.99	-0.06	0.00	-0.07

Notes : The table reports the long-run elasticities of the outcomes indicated in the column headings with respect to the price of electricity. The table is constructed similarly to Table 2a, except that the elasticities are calculated from the estimates of equation (3) rather than equation (2).

Table 3b. Long-Run Elasticities with Respect to Natural Gas Prices

Industry Name	NAICS	Natural Gas Cost Share	Output	Employment	Value Added
Breakfast Cereal	311230 (L1)	0.60	0.07	0.10	0.00
Sugar	311310 (L2)	1.34	-0.05	-0.05	-0.05
Fruit and Veg	311421	1.61	-0.12	-0.15*	-0.10
Dried and Dehydrated Food	311423	1.61	-0.07	-0.08	-0.12
Creamy Butter	311512 (L1)	0.88	0.07	0.10	0.00
Cheese	311513	0.81	-0.05	-0.01	-0.11
Dairy Product	311514	1.29	-0.05	-0.05	-0.02
Slaughtering	311611	0.78	-0.03	0.06	-0.24
Meat Processing	311613	0.78	-0.04	-0.08	-0.10
Poultry Processing	311615	0.95	-0.24	-0.07	-0.73*
Nuts and Peanut Butter	311911	0.72	0.03	0.09	-0.11
Other Snack Food	311919 (L2)	0.72	-0.05	-0.05	-0.05
Perishable Prepared Food	311991	0.88	-0.01	-0.01	-0.08
All Other Misc. Food	311999	0.88	-0.08	-0.10*	-0.10
Breweries	312120 (L2)	0.86	-0.05	-0.05	-0.05
Wineries	312130	0.40	-0.17	-0.22*	-0.11
Paper Mills	322121	3.67	-0.10	-0.09	0.01
Paperboard Mills	322130	5.78	-0.05	-0.08	-0.11
Setup Paperboard Box	322213 (L2)	0.74	-0.05	-0.05	-0.05
Petroleum Refineries	324110	1.42	-0.08	-0.10	-0.10
Asphalt	324121	3.11	-0.06	-0.08	-0.11
Other Petroleum Products	324199 (L2)	0.08	-0.05	-0.05	-0.05
Industrial Gas	325120	10.62	-0.06	-0.08	-0.11
All Other Basic Inorg. Chem.	325188	2.55	-0.02	-0.04	-0.03
Ethanol	325193 (L3)	4.98	-0.04	-0.08	-0.10
All Other Basic Org. Chem.	325199	2.67	0.11	0.04	-0.09
Nitrogenous Fertilizer	325311	6.15	0.37	0.03	0.23
Pharmaceutical Preparation	325412	0.26	0.01	0.08	-0.15

Table 3b (continued).

Industry Name	NAICS	Natural Gas Cost Share	Output	Employment	Value added
Biological Product	325414	0.55	-0.05	-0.01	-0.12
Flat Glass	327211 (L3)	14.82	-0.04	-0.08	-0.10
Glass Container	327213 (L3)	9.38	-0.04	-0.08	-0.10
Cement	327310	1.26	-0.07	-0.09	-0.12
Lime	327410 (L3)	0.71	-0.04	-0.08	-0.10
Gypsum Product	327420	10.69	0.01	-0.07	-0.06
Mineral Wool	327993	5.29	-0.07	-0.09	-0.12
Iron and Steel Mills and Ferroalloy	331111	2.06	-0.00	-0.03	-0.04
Rolled Steel	331221 (L2)	1.20	-0.05	-0.05	-0.05
Secondary Aluminum Smelt/Alloying	331314	3.88	-0.17	-0.13	0.04
Aluminum Extruded Product	331316	2.10	-0.02	-0.03	-0.09
Secondary Nonferrous Metal Proc.	331492	0.98	0.12	0.05	-0.09
Iron Foundries	331511	1.60	-0.05	-0.07	-0.09
Forging and Stamping	332111	2.12	0.05	0.00	-0.06
Nonferrous Forging	332112	2.12	0.06	0.01	-0.07
Hardware	332510	0.63	0.12	0.05	0.16
Turbines	333611 (L1)	0.39	0.07	0.10	0.00
Automobiles	336111 (L1)	0.32	0.07	0.10	0.00
All Other Motor Vehicle Parts	336399	0.56	0.06	0.03	0.06
Aircraft	336411	0.20	0.02	0.08	-0.13
Missiles	336414 (L1)	0.29	0.07	0.10	0.00
Average		2.41	-0.02	-0.03	-0.08

Notes : The table is constructed similarly to Table 3a except reporting natural gas cost shares and elasticities with respect to natural gas prices rather than electricity prices.

Table 4. Correlations Between Cost Shares, Short-Run Outcomes, and Long-Run Outcomes

Panel A. Electricity

	Cost share	Short run / employment	Short run / output	Short run / value added	Long run / employment	Long run / output	Long run / value added
Cost share	1.00						
Short run / employment	-0.34	1.00					
Short run / output	-0.26	0.95	1.00				
Short run / value added	-0.37	0.99	0.97	1.00			
Long run / employment	-0.58	0.66	0.64	0.69	1.00		
Long run / output	-0.51	0.74	0.64	0.75	0.77	1.00	
Long run / value added	-0.45	0.59	0.45	0.58	0.63	0.85	1.00

Panel B. Natural Gas

	Cost share	Short run / employment	Short run / output	Short run / value added	Long run / employment	Long run / output	Long run / value added
Cost share	1.00						
Short run / employment	-0.35	1.00					
Short run / output	-0.41	0.88	1.00				
Short run / value added	-0.43	0.73	0.66	1.00			
Long run / employment	-0.50	0.38	0.31	0.36	1.00		
Long run / output	-0.21	0.27	0.15	0.25	0.87	1.00	
Long run / value added	-0.04	0.42	0.37	0.51	0.32	0.43	1.00

Notes : The table reports the Spearman rank correlations between the elasticities indicated in the column and row headings. Panel A shows results for elasticities with respect to the electricity price and Panel B shows results for elasticities with respect to the natural gas price. The column short run / employment shows the correlation between the short-run elasticity of employment to the corresponding energy price, and the variables indicated in the row headings, and likewise for the other columns. Cost share is the electricity cost share in panel A and the natural gas cost share in panel B.

Table 5. Short-Run Percentage Changes of Output, Employment, and Value Caused by Energy Price Increases

Industry Name	NAICS	Output	Employment	Value Added
Glass Container	327213	-17.10%	-13.31%	-16.29%
Paperboard Mills	322130	-14.24%	-11.10%	-13.29%
Automobiles	336111	-12.68%	-6.47%	-11.43%
Iron and Steel Mills and Ferroalloy	331111	-12.16%	-7.64%	-11.26%
Poultry Processing	311615	-10.71%	-9.69%	-10.38%
Mineral Wool	327993	-10.37%	-7.49%	-11.30%
Ethanol	325193 (S2)	-10.33%	-8.02%	-9.51%
Flat Glass	327211 (S2)	-10.33%	-8.02%	-9.51%
Lime	327410 (S2)	-10.33%	-8.02%	-9.51%
Iron Foundries	331511	-9.83%	-7.01%	-9.11%
Nitrogenous Fertilizer	325311	-9.45%	-5.32%	-5.01%
Cement	327310	-9.28%	-6.41%	-11.26%
Breakfast Cereal	311230 (S1)	-8.12%	-5.08%	-7.01%
Creamy Butter	311512 (S1)	-8.12%	-5.08%	-7.01%
Breweries	312120 (S1)	-8.12%	-5.08%	-7.01%
Turbines	333611 (S1)	-8.12%	-5.08%	-7.01%
Nuts and Peanut Butter	311911	-7.82%	-4.11%	-6.60%
Industrial Gas	325120	-7.65%	-4.06%	-7.04%
All Other Basic Org. Chem.	325199	-7.61%	-3.68%	-5.38%
Meat Processing	311613	-7.48%	-6.37%	-6.62%
Gypsum Product	327420	-7.30%	-6.14%	-6.34%
Forging and Stamping	332111	-6.72%	-3.86%	-6.03%
All Other Basic Inorg. Chem.	325188	-6.64%	-4.18%	-6.59%
Paper Mills	322121	-6.64%	-4.68%	-7.26%
Other Petroleum Products	324199	-6.06%	-3.93%	-6.73%
Petroleum Refineries	324110	-6.04%	-3.65%	-3.57%
Nonferrous Forging	332112	-5.96%	-3.27%	-4.93%
Aluminum Extruded Product	331316	-5.40%	-3.61%	-5.71%

Table 5 (continued).

Industry Name	NAICS	Output	Employment	Value Added
Secondary Aluminum Smelt/Alloying	331314	-5.35%	-4.00%	-6.44%
All Other Misc. Food	311999	-5.18%	-3.27%	-2.97%
Pharmaceutical Preparation	325412	-4.73%	-3.06%	-3.83%
Dairy Product	311514	-3.69%	-1.19%	-2.93%
Aircraft	336411	-3.50%	-2.00%	-3.04%
Secondary Nonferrous Metal Proc.	331492	-3.24%	-1.20%	-6.27%
Fruit and Veg	311421	-3.15%	-3.00%	-0.06%
All Other Motor Vehicle Parts	336399	-2.80%	-1.63%	-1.52%
Slaughtering	311611	-2.44%	-1.88%	-0.97%
Perishable Prepared Food	311991	-2.20%	-0.33%	-2.85%
Sugar	311310	-2.07%	-0.90%	-1.34%
Dried and Dehydrated Food	311423	-2.05%	-2.23%	-1.56%
Asphalt	324121	-1.77%	-2.54%	-1.21%
Missiles	336414	-1.27%	-0.09%	-0.24%
Other Snack Food	311919	-1.26%	0.76%	-1.14%
Hardware	332510	-1.04%	-0.35%	-0.23%
Cheese	311513	1.05%	1.92%	1.45%
Wineries	312130	2.00%	1.92%	1.84%
Biological Product	325414	2.50%	3.17%	2.66%
Setup Paperboard Box	322213	3.29%	4.02%	3.50%
Rolled Steel	331221	8.55%	7.13%	7.47%
Average		-5.69%	-3.65%	-5.07%

Notes : The table reports the simulated short-run percentage change in the outcome indicated in the column heading caused by an energy price increase in 2009. The energy price increases are proportional to a carbon dioxide emissions price of $10 per ton, and the percentage changes are calculated using the baseline estimates of equation (2) (five cost-share groups, industry cost shares, and 500 miles). For industries in the same bundle a common percentage change is reported.

Table 6. Long-Run Impacts of Energy Price Increases

Industry Name	NAICS	Output	Employment	Value Added
Hardware	332510	-0.71%	1.03%	-3.71%
Sugar	311310 (L2)	-0.52%	-0.19%	-0.06%
Other Snack Food	311919 (L2)	-0.52%	-0.19%	-0.06%
Breweries	312120 (L2)	-0.52%	-0.19%	-0.06%
Setup Paperboard Box	322213 (L2)	-0.52%	-0.19%	-0.06%
Other Petroleum Products	324199 (L2)	-0.52%	-0.19%	-0.06%
Rolled Steel	331221 (L2)	-0.52%	-0.19%	-0.06%
Aluminum Extruded Product	331316	-0.07%	-1.17%	-0.03%
All Other Motor Vehicle Parts	336399	-0.06%	-4.78%	-0.22%
Slaughtering	311611	-0.04%	-1.18%	0.19%
Secondary Aluminum Smelt/Alloying	331314	-0.03%	-0.12%	-0.01%
Nitrogenous Fertilizer	325311	-0.02%	0.00%	-0.02%
Aircraft	336411	-0.01%	-34.76%	0.80%
Paper Mills	322121	-0.01%	-0.08%	-0.01%
Biological Product	325414	-0.01%	-0.04%	0.02%
Meat Processing	311613	-0.01%	-0.04%	-0.02%
Perishable Prepared Food	311991	-0.01%	-0.01%	0.00%
Gypsum Product	327420	-0.01%	-0.03%	-0.03%
Petroleum Refineries	324110	0.00%	0.20%	-0.03%
Asphalt	324121	0.00%	-0.04%	-0.01%
Nonferrous Forging	332112	0.00%	0.00%	-0.01%
Dairy Product	311514	0.00%	0.00%	0.01%
Pharmaceutical Preparation	325412	0.01%	-0.80%	0.25%
Forging and Stamping	332111	0.01%	0.02%	0.09%
All Other Misc. Food	311999	0.01%	0.26%	0.00%
Wineries	312130	0.02%	0.27%	0.01%
Secondary Nonferrous Metal Proc.	331492	0.02%	0.02%	-0.04%
Dried and Dehydrated Food	311423	0.02%	0.00%	0.06%

Table 6 (continued).

Industry Name	NAICS	Output	Employment	Value Added
All Other Basic Org. Chem.	325199	0.02%	0.02%	-0.01%
Industrial Gas	325120	0.03%	0.11%	0.04%
Cement	327310	0.03%	0.12%	0.06%
Iron and Steel Mills and Ferroalloy	331111	0.05%	0.18%	0.08%
Ethanol	325193 (L3)	0.05%	0.26%	0.10%
Flat Glass	327211 (L3)	0.05%	0.26%	0.10%
Glass Container	327213 (L3)	0.05%	0.26%	0.10%
Lime	327410 (L3)	0.05%	0.26%	0.10%
All Other Basic Inorg. Chem.	325188	0.07%	0.29%	0.11%
Iron Foundries	331511	0.07%	0.23%	0.15%
Paperboard Mills	322130	0.08%	0.40%	0.17%
Cheese	311513	0.08%	-0.07%	0.32%
Mineral Wool	327993	0.10%	0.26%	0.20%
Poultry Processing	311615	0.10%	0.22%	0.43%
Nuts and Peanut Butter	311911	0.12%	-1.79%	1.05%
Fruit and Veg	311421	0.18%	2.32%	0.51%
Breakfast Cereal	311230 (L1)	2.05%	-4.59%	-0.73%
Creamy Butter	311512 (L1)	2.05%	-4.59%	-0.73%
Turbines	333611 (L1)	2.05%	-4.59%	-0.73%
Automobiles	336111 (L1)	2.05%	-4.59%	-0.73%
Missiles	336414 (L1)	2.05%	-4.59%	-0.73%
Average		0.15%	-1.27%	-0.07%

Notes : The table reports the simulated long-run percentage change in the outcome indicated in the column heading caused by an energy price increase in 2009. The energy price increases are proportional to a carbon dioxide emissions price of $10 per ton, and the percentage changes are calculated using the baseline estimates of equation (3) (five cost-share groups, industry cost shares, and 500 miles). For industries in the same bundle a common percentage change is reported.

Table 7. Correlations Between Cost Shares and Simulation Outcomes

	Cost share	Short run / output	Short run / employment	Short run / value added	Long run / output	Long run / employment	Long run / value added
Cost share	1.00						
Short run / output	-0.43	1.00					
Short run / employment	-0.49	0.97	1.00				
Short run / value added	-0.42	0.95	0.94	1.00			
Long run / output	0.09	-0.53	-0.48	-0.48	1.00		
Long run / employment	0.55	-0.26	-0.31	-0.22	0.20	1.00	
Long run / value added	0.29	-0.23	-0.26	-0.19	0.32	0.43	1.00

Notes : The table reports the Spearman rank correlations between the outcomes indicated in the column and row headings. The column short run / employment shows the correlation between the short-run change in employment caused by energy price increases induced by a carbon price of $10 per ton of carbon dioxide, and the variables indicated in the row headings, and likewise for the other columns. Cost share is the combined electricity and natural gas cost share.

Table 8. Distribution of Impacts Across Models

Num. of groups	Cost share	Distance	Weighted	
				Panel A. Output, short run
5	Industry	500	No	.H..........M...........ZL.......................
3	Industry	500	No	.....H.......M.......L..Z........................
1	Industry	500	No	............H.M.L.......Z........................
5	Plant	500	No	.........H....M.........ZL.......................
5	Industry	250	No	H..........M...........LZ........................
5	Industry	500	Yes	H.......M...............Z...L....................
				Panel B. Output, long run
5	Industry	500	No	.......................HM.L......................
3	Industry	500	No	.......................XL........................
1	Industry	500	No	.......................XZ.L......................
5	Plant	500	No	.....................H.MZL.......................
5	Industry	250	No	.......................HM....L...................
5	Industry	500	Yes	....................H..MZ..L.....................
				Panel C. Employment, short run
5	Industry	500	No	.......H........M.......Z..L.....................
3	Industry	500	No	..........H......M.....LZ........................
1	Industry	500	No	................HML.....Z........................
5	Plant	500	No	............H....M......Z.L......................
5	Industry	250	No	.......H........M.......ZL.......................
5	Industry	500	Yes	......H.....M...........Z.L......................
				Panel D. Employment, long run
5	Industry	500	No	...............H.......ML........................
3	Industry	500	No	.......................XZ..L.....................
1	Industry	500	No	.......................XZ........................
5	Plant	500	No	....................H..ML........................
5	Industry	250	No	.................H......ML.......................
5	Industry	500	Yes	...................H.M..L........................
				Panel E. Value added, short run
5	Industry	500	No	..H..........M..........Z.L......................
3	Industry	500	No	......H........M.......LZ........................
1	Industry	500	No	..............H.ML......Z........................
5	Plant	500	No	........H......M........Z.L......................
5	Industry	250	No	H............M..........L........................
5	Industry	500	Yes	......H.........M.......Z...L....................

Table 8 (continued).

				Panel F. Value added, long run
5	Industry	500	No	......................H.X........................
3	Industry	500	No	.......................HX........................
1	Industry	500	No	..........H............MZ.....L..................
5	Plant	500	No	.....................H.MZ....L...................
5	Industry	250	No	......................H.X........................
5	Industry	500	Yes	.........H...........M..Z......L.................

Notes : Each panel reports the simulated effects of the indicated outcome in the short run (using equation (2)) or the long run (using equation (3)). Each row reports the results of a different specification, with the first four columns defining the specification. The graph at the right of the table displays the estimated percentage change, with Z indicating no change. Each dot represents 0.5 percentage points, and the scale ranges from -12 to 12 percent. The 49 industry impacts for the model were sorted, from most negative to most positive, and three averages were calculated. The H value is the average of values 3-7 (the most negative). The M value is the average of values 13-37. The L value is the average of values 43-47 (the least negative or most positive).

Table 9a. Cross-Model Correlations Across Models of Short-Run Elasticities to Electricity Prices

	Baseline	3 groups	1 group	250 miles	Weighted
			Panel A. Output		
	Baseline	3 groups	1 group	250 miles	Weighted
Baseline	1.00				
3 groups	0.61	1.00			
1 group	0.50	0.56	1.00		
250 miles	1.00	0.62	0.49	1.00	
Weighted	0.34	0.02	-0.36	0.36	1.00
			Panel B. Employment		
	Baseline	3 groups	1 group	250 miles	Weighted
Baseline	1.00				
3 groups	0.78	1.00			
1 group	-0.55	-0.55	1.00		
250 miles	1.00	0.78	-0.55	1.00	
Weighted	0.27	0.10	0.28	0.27	1.00
			Panel C. Value Added		
	Baseline	3 groups	1 group	250 miles	Weighted
Baseline	1.00				
3 groups	0.72	1.00			
1 group	0.56	0.58	1.00		
250 miles	1.00	0.72	0.56	1.00	
Weighted	0.32	0.14	-0.18	0.32	1.00

Notes : The table reports correlations of short-run elasticities with respect to electricity prices estimated from alternative versions of equation (2).

Table 9b. Cross-Model Correlations of Short-Run Elasticities to Natural Gas Prices

	Baseline	3 groups	1 group	250 miles	Weighted
			Panel A. Output		
	Baseline	3 groups	1 group	250 miles	Weighted
Baseline	1.00				
3 groups	0.45	1.00			
1 group	0.35	0.22	1.00		
250 miles	0.85	0.44	0.37	1.00	
Weighted	0.60	0.06	0.24	0.47	1.00
			Panel B. Employment		
	Baseline	3 groups	1 group	250 miles	Weighted
Baseline	1.00				
3 groups	0.47	1.00			
1 group	0.31	0.22	1.00		
250 miles	0.94	0.52	0.27	1.00	
Weighted	0.81	0.40	0.29	0.74	1.00
			Panel C. Value Added		
	Baseline	3 groups	1 group	250 miles	Weighted
Baseline	1.00				
3 groups	0.54	1.00			
1 group	0.51	0.05	1.00		
250 miles	0.80	0.34	0.44	1.00	
Weighted	0.35	-0.26	0.39	0.35	1.00

Notes : The table is constructed similarly to Table 9a, except reporting short-run elasticities with respect to natural gas prices rather than electricity prices.

Table 10a. Cross-Model Correlations of Long-Run Elasticities to Electricity Prices

	Baseline	3 groups	1 group	250 miles	Weighted
			Panel A. Output		
	Baseline	3 groups	1 group	250 miles	Weighted
Baseline	1.00				
3 groups	0.84	1.00			
1 group	0.69	0.70	1.00		
250 miles	0.99	0.86	0.70	1.00	
Weighted	0.79	0.63	0.61	0.79	1.00
			Panel B. Employment		
	Baseline	3 groups	1 group	250 miles	Weighted
Baseline	1.00				
3 groups	0.90	1.00			
1 group	-0.72	-0.69	1.00		
250 miles	1.00	0.88	-0.71	1.00	
Weighted	0.33	0.25	-0.45	0.31	1.00
			Panel C. Value Added		
	Baseline	3 groups	1 group	250 miles	Weighted
Baseline	1.00				
3 groups	0.70	1.00			
1 group	0.52	0.55	1.00		
250 miles	1.00	0.71	0.51	1.00	
Weighted	0.69	0.66	0.71	0.68	1.00

Notes : The table reports correlations of long-run elasticities with respect to electricity prices estimated from alternative versions of equation (3). The table is constructed similarly to Table 9a except reporting long-run elasticities rather than short-run elasticities.

Table 10b. Cross-Model Correlations of Long-Run Elasticities to Natural Gas Prices

	Baseline	3 groups	1 group	250 miles	Weighted
			Panel A. Output		
	Baseline	3 groups	1 group	250 miles	Weighted
Baseline	1.00				
3 groups	0.58	1.00			
1 group	0.22	0.29	1.00		
250 miles	0.98	0.56	0.16	1.00	
Weighted	0.01	-0.03	0.26	-0.09	1.00
			Panel B. Employment		
	Baseline	3 groups	1 group	250 miles	Weighted
Baseline	1.00				
3 groups	0.58	1.00			
1 group	0.60	0.36	1.00		
250 miles	0.99	0.57	0.54	1.00	
Weighted	0.51	0.44	0.09	0.55	1.00
			Panel C. Value Added		
	Baseline	3 groups	1 group	250 miles	Weighted
Baseline	1.00				
3 groups	-0.05	1.00			
1 group	0.04	-0.61	1.00		
250 miles	0.82	-0.10	-0.05	1.00	
Weighted	0.07	0.36	-0.33	0.05	1.00

Notes : The table is constructed similarly to Table 10a, except reporting long-run elasticities with respect to natural gas prices rather than electricity prices.

Table 11. Cross-Model Correlations of Short-Run Impacts of Energy Price Increases

	Baseline	3 groups	1 group	Plant cost share	250 miles	Weighted
Panel A. Output						
Baseline	1.00					
3 groups	0.83	1.00				
1 group	0.62	0.67	1.00			
Plant cost share	0.79	0.68	0.65	1.00		
250 miles	0.96	0.81	0.61	0.77	1.00	
Weighted	0.50	0.17	0.15	0.51	0.44	1.00
Panel B. Employment						
Baseline	1.00					
3 groups	0.79	1.00				
1 group	0.62	0.57	1.00			
Plant cost share	0.79	0.55	0.52	1.00		
250 miles	0.97	0.76	0.60	0.82	1.00	
Weighted	0.66	0.44	0.33	0.59	0.63	1.00
Panel C. Value Added						
Baseline	1.00					
3 groups	0.84	1.00				
1 group	0.68	0.61	1.00			
Plant cost share	0.78	0.70	0.66	1.00		
250 miles	0.96	0.81	0.71	0.75	1.00	
Weighted	0.44	0.24	0.35	0.50	0.44	1.00

Notes : The table reports correlations of simulated short-run effects of energy price increases induced by a carbon price of $10 per ton of carbon dioxide, based on alternative versions of equation (2). Panel A shows results for output, Panel B for employment, and Panel C for value added. The baseline model includes five cost share groups, industry-level cost shares, and a distance of 500 miles to determine which plants. Observations are unweighted in the baseline. Each column and row includes outcomes from the indicated variation of the baseline model, with the final column and row weighting observations by the plant average of the dependent variable.

Table 12. Cross-Model Correlations of Long-Run Impacts of Energy Price Increases

Panel A. Output

	Baseline	3 groups	1 group	Plant cost share	250 miles	Weighted
Baseline	1.00					
3 groups	-0.09	1.00				
1 group	-0.16	0.34	1.00			
Plant cost share	-0.14	0.14	0.22	1.00		
250 miles	0.99	-0.09	-0.16	-0.13	1.00	
Weighted	-0.55	0.25	0.40	0.09	-0.54	1.00

Panel B. Employment

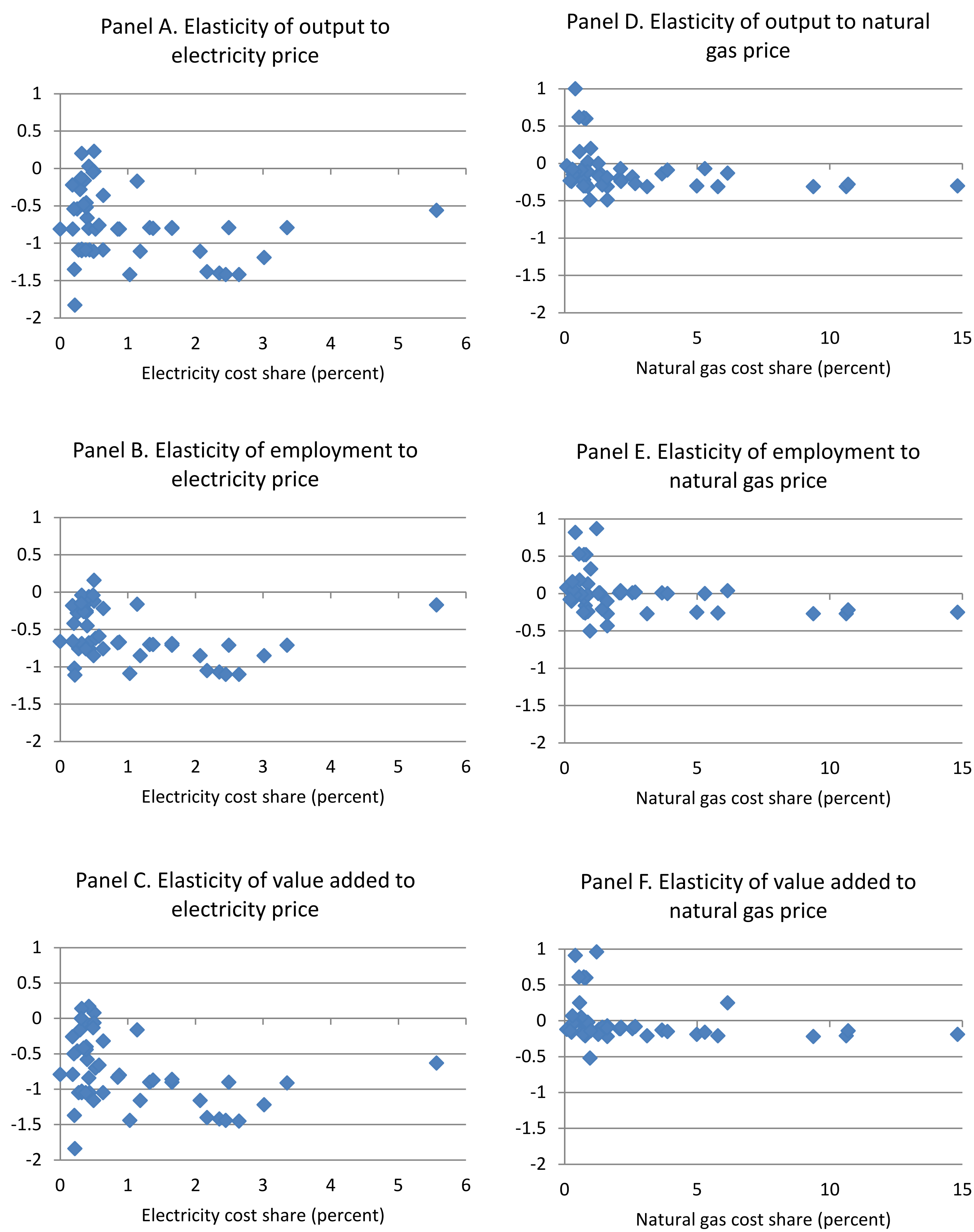
	Baseline	3 groups	1 group	Plant cost share	250 miles	Weighted
Baseline	1.00					
3 groups	0.15	1.00				
1 group	-0.35	0.06	1.00			
Plant cost share	-0.42	0.09	0.50	1.00		
250 miles	0.74	0.10	-0.16	-0.42	1.00	
Weighted	-0.33	-0.17	0.14	0.26	-0.44	1.00

Panel C. Value Added

	Baseline	3 groups	1 group	Plant cost share	250 miles	Weighted
Baseline	1.00					
3 groups	-0.28	1.00				
1 group	0.00	0.09	1.00			
Plant cost share	-0.54	0.49	-0.13	1.00		
250 miles	0.95	-0.18	-0.14	-0.39	1.00	
Weighted	0.02	-0.27	-0.13	0.19	0.08	1.00

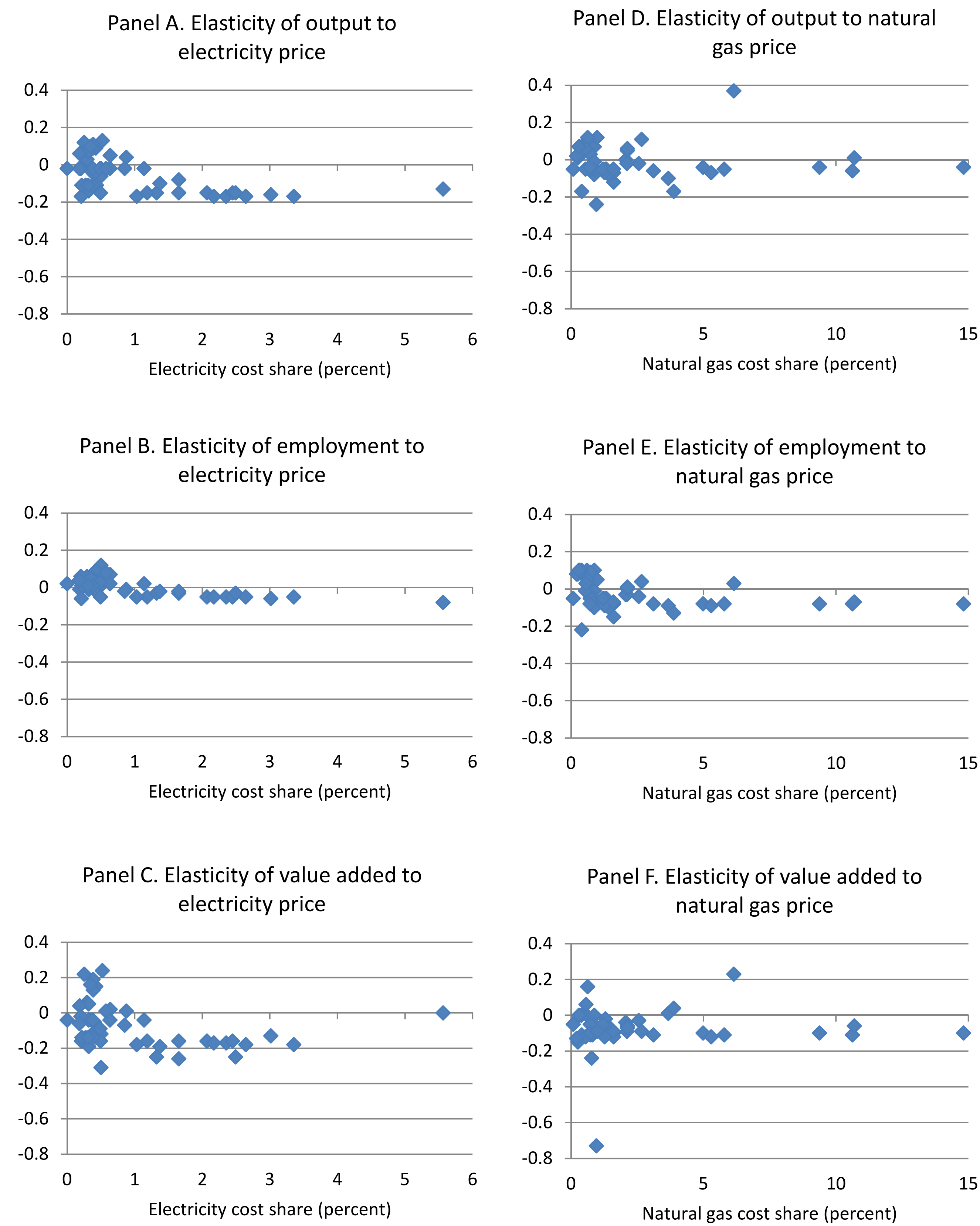
Notes : The table reports correlations of simulated long-run effects of energy price increases induced by a carbon price of $10 per ton of carbon dioxide, based on alternative versions of equation (3). The table is constructed similarly to Table 11.

Figure 1. Short-Run Energy Price Elasticities vs. Energy Cost Shares



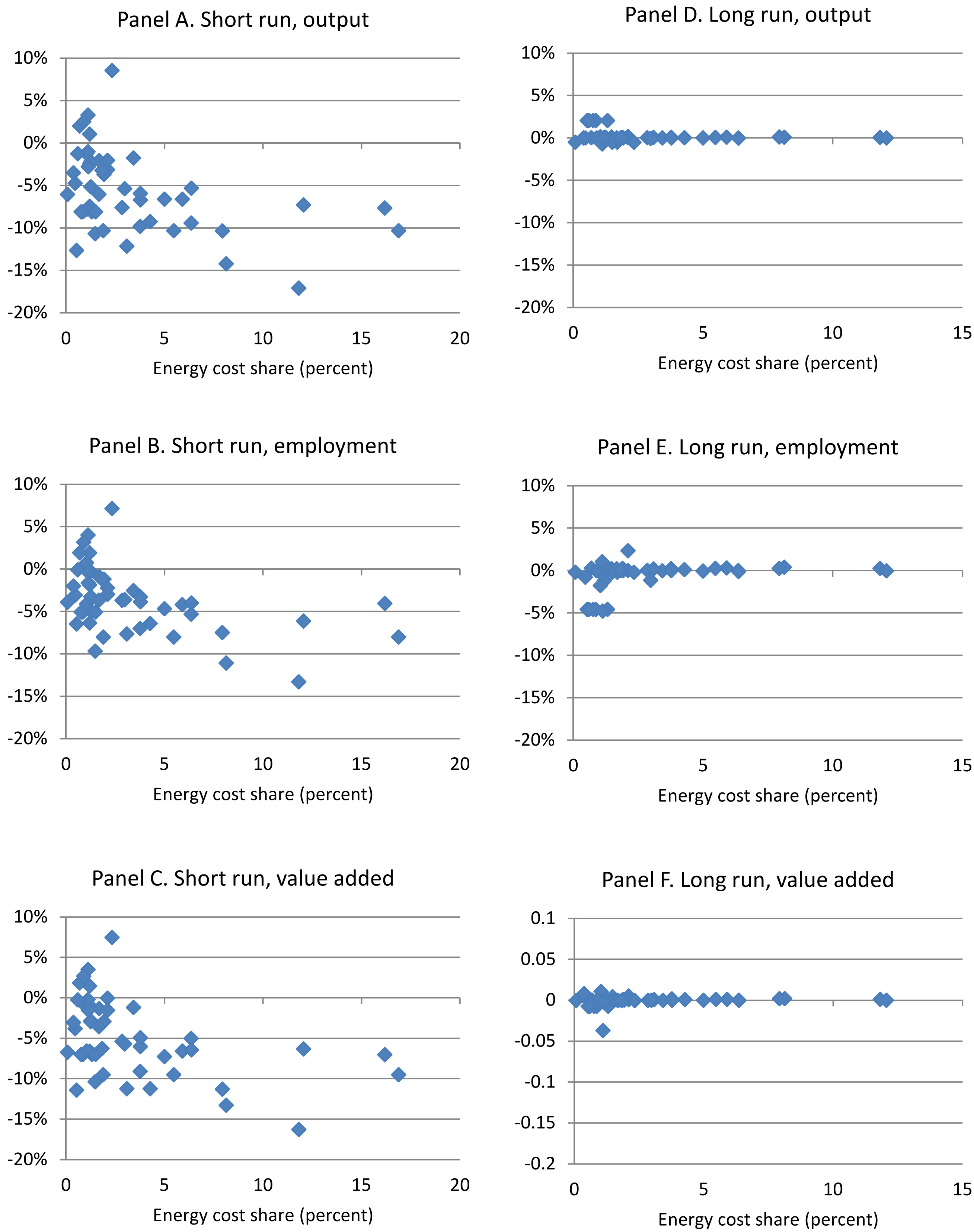
Notes : The figures plot the estimated elasticities against the corresponding cost shares that are reported in Table 2.

Figure 2. Long-Run Energy Price Elasticities vs. Energy Cost Shares



Notes : The figures plot the estimated elasticities against the corresponding cost shares that are reported in Table 3.

Figure 3. Simulated Short- and Long-Run Impacts vs. Energy Cost Shares



Notes : The figures plot the simulated impacts of energy price increases against industry energy cost shares (the sum of electricity and natural gas), which are reported in Tables 5 and 6.

Table A1. Estimated Impacts on Value-Added for $22.62 Carbon Price

		Allowance Reduction (%)									
Industry Name	NAICS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%
Breakfast Cereal	311230 (S1)	-15.5%	-14.0%	-12.5%	-11.0%	-9.4%	-7.9%	-6.4%	-4.8%	-3.2%	-1.6%
Sugar	311310	-2.9%	-2.6%	-2.4%	-2.1%	-1.8%	-1.5%	-1.2%	-0.9%	-0.6%	-0.3%
Fruit and Veg	311421	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	0.0%	0.0%	0.0%
Dried and Dehydrated Food	311423	-3.4%	-3.0%	-2.7%	-2.4%	-2.1%	-1.8%	-1.4%	-1.1%	-0.7%	-0.4%
Creamy Butter	311512 (S1)	-15.5%	-14.0%	-12.5%	-11.0%	-9.4%	-7.9%	-6.4%	-4.8%	-3.2%	-1.6%
Cheese	311513	3.0%	2.8%	2.5%	2.2%	1.9%	1.6%	1.3%	1.0%	0.7%	0.3%
Dairy Product	311514	-6.4%	-5.8%	-5.2%	-4.6%	-3.9%	-3.3%	-2.7%	-2.0%	-1.3%	-0.7%
Slaughtering	311611	-2.1%	-1.9%	-1.7%	-1.5%	-1.3%	-1.1%	-0.9%	-0.7%	-0.5%	-0.2%
Meat Processing	311613	-14.5%	-13.1%	-11.7%	-10.3%	-8.9%	-7.5%	-6.0%	-4.5%	-3.0%	-1.5%
Poultry Processing	311615	-22.6%	-20.5%	-18.3%	-16.1%	-13.9%	-11.7%	-9.4%	-7.1%	-4.8%	-2.4%
Nuts and Peanut Butter	311911	-14.5%	-13.1%	-11.7%	-10.3%	-8.9%	-7.4%	-6.0%	-4.5%	-3.0%	-1.5%
Other Snack Food	311919	-2.1%	-2.0%	-1.8%	-1.7%	-1.5%	-1.3%	-1.0%	-0.8%	-0.6%	-0.3%
Perishable Prepared Food	311991	-6.2%	-5.6%	-5.0%	-4.4%	-3.8%	-3.2%	-2.6%	-2.0%	-1.3%	-0.7%
All Other Misc. Food	311999	-6.5%	-5.9%	-5.3%	-4.6%	-4.0%	-3.3%	-2.7%	-2.0%	-1.4%	-0.7%
Breweries	312120 (S1)	-15.5%	-14.0%	-12.5%	-11.0%	-9.4%	-7.9%	-6.4%	-4.8%	-3.2%	-1.6%
Wineries	312130	3.9%	3.6%	3.2%	2.8%	2.5%	2.1%	1.7%	1.3%	0.9%	0.4%
Paper Mills	322121	-15.9%	-14.4%	-12.9%	-11.3%	-9.8%	-8.2%	-6.6%	-5.0%	-3.3%	-1.7%
Paperboard Mills	322130	-29.2%	-26.4%	-23.6%	-20.8%	-17.9%	-15.0%	-12.1%	-9.1%	-6.1%	-3.1%
Setup Paperboard Box	322213	7.4%	6.8%	6.1%	5.4%	4.7%	3.9%	3.2%	2.4%	1.6%	0.8%
Petroleum Refineries	324110	-7.8%	-7.1%	-6.3%	-5.6%	-4.8%	-4.0%	-3.2%	-2.4%	-1.6%	-0.8%
Asphalt	324121	-2.6%	-2.3%	-2.1%	-1.9%	-1.6%	-1.4%	-1.1%	-0.8%	-0.6%	-0.3%
Other Petroleum Products	324199	-14.8%	-13.4%	-11.9%	-10.5%	-9.1%	-7.6%	-6.1%	-4.6%	-3.1%	-1.6%
Industrial Gas	325120	-15.4%	-13.9%	-12.5%	-11.0%	-9.5%	-7.9%	-6.4%	-4.8%	-3.2%	-1.6%
All Other Basic Inorg. Chem.	325188	-14.5%	-13.1%	-11.7%	-10.3%	-8.9%	-7.4%	-6.0%	-4.5%	-3.0%	-1.5%
Ethanol	325193 (S2)	-20.9%	-18.9%	-16.9%	-14.8%	-12.8%	-10.7%	-8.6%	-6.5%	-4.4%	-2.2%
All Other Basic Org. Chem.	325199	-11.8%	-10.7%	-9.6%	-8.4%	-7.2%	-6.1%	-4.9%	-3.7%	-2.5%	-1.2%
Nitrogenous Fertilizer	325311	-11.2%	-10.1%	-9.0%	-7.9%	-6.8%	-5.7%	-4.5%	-3.4%	-2.3%	-1.1%
Pharmaceutical Preparation	325412	-8.4%	-7.6%	-6.8%	-6.0%	-5.1%	-4.3%	-3.5%	-2.6%	-1.8%	-0.9%

Table A1 (continued).

		Allowance Reduction (%)									
Industry Name	NAICS	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%
Biological Product	325414	5.7%	5.1%	4.6%	4.1%	3.5%	3.0%	2.4%	1.8%	1.2%	0.6%
Flat Glass	327211 (S2)	-20.9%	-18.9%	-16.9%	-14.8%	-12.8%	-10.7%	-8.6%	-6.5%	-4.4%	-2.2%
Glass Container	327213	-35.7%	-32.3%	-28.9%	-25.4%	-21.9%	-18.4%	-14.8%	-11.1%	-7.5%	-3.8%
Cement	327310	-24.7%	-22.3%	-20.0%	-17.6%	-15.1%	-12.7%	-10.2%	-7.7%	-5.2%	-2.6%
Lime	327410 (S2)	-20.9%	-18.9%	-16.9%	-14.8%	-12.8%	-10.7%	-8.6%	-6.5%	-4.4%	-2.2%
Gypsum Product	327420	-13.9%	-12.6%	-11.2%	-9.9%	-8.5%	-7.1%	-5.7%	-4.3%	-2.9%	-1.5%
Mineral Wool	327993	-24.8%	-22.4%	-20.1%	-17.6%	-15.2%	-12.7%	-10.2%	-7.7%	-5.2%	-2.6%
Iron and Steel Mills and Ferroalloy	331111	-24.8%	-22.4%	-20.0%	-17.6%	-15.2%	-12.7%	-10.2%	-7.7%	-5.2%	-2.6%
Rolled Steel	331221	16.1%	14.6%	13.1%	11.6%	10.0%	8.4%	6.8%	5.1%	3.5%	1.7%
Secondary Aluminum Smelt/Alloying	331314	-14.1%	-12.8%	-11.4%	-10.0%	-8.7%	-7.3%	-5.8%	-4.4%	-3.0%	-1.5%
Aluminum Extruded Product	331316	-12.5%	-11.3%	-10.1%	-8.9%	-7.7%	-6.4%	-5.2%	-3.9%	-2.6%	-1.3%
Secondary Nonferrous Metal Proc.	331492	-13.7%	-12.4%	-11.1%	-9.8%	-8.4%	-7.1%	-5.7%	-4.3%	-2.9%	-1.4%
Iron Foundries	331511	-20.0%	-18.1%	-16.2%	-14.2%	-12.3%	-10.3%	-8.3%	-6.2%	-4.2%	-2.1%
Forging and Stamping	332111	-13.3%	-12.0%	-10.7%	-9.4%	-8.1%	-6.8%	-5.5%	-4.1%	-2.8%	-1.4%
Nonferrous Forging	332112	-10.8%	-9.8%	-8.8%	-7.7%	-6.6%	-5.6%	-4.5%	-3.4%	-2.3%	-1.1%
Hardware	332510	-0.5%	-0.5%	-0.4%	-0.4%	-0.3%	-0.3%	-0.2%	-0.2%	-0.1%	0.0%
Turbines	333611 (S1)	-15.5%	-14.0%	-12.5%	-11.0%	-9.4%	-7.9%	-6.4%	-4.8%	-3.2%	-1.6%
Automobiles	336111	-25.2%	-22.8%	-20.3%	-17.9%	-15.4%	-12.9%	-10.4%	-7.8%	-5.2%	-2.6%
All Other Motor Vehicle Parts	336399	-3.6%	-3.2%	-2.8%	-2.5%	-2.1%	-1.7%	-1.4%	-1.0%	-0.7%	-0.3%
Aircraft	336411	-6.6%	-6.0%	-5.4%	-4.7%	-4.1%	-3.4%	-2.8%	-2.1%	-1.4%	-0.7%
Missiles	336414	-0.5%	-0.5%	-0.4%	-0.4%	-0.3%	-0.3%	-0.2%	-0.2%	-0.1%	-0.1%
	Average	-11.1%	-10.1%	-9.0%	-7.9%	-6.8%	-5.7%	-4.6%	-3.5%	-2.3%	-1.2%

Notes: The table reports the estimated impact on value-added for each industry of the indicated carbon price and allowance reductions (0% to 90%). The estimated impacts are based upon the elasticities reported in Table 2, using the baseline specification (5 cost-share groups, industry cost shares, and 500 miles). Industries in the same bundle have the same values. The bottom of the table reports the average impact across all 49 industries.

The elasticities (electricity and natural gas) in Table 2 show how an energy price change affects the outcome variable, in this case value-added [dln(value-added)/dln(price)]. The estimated impact on log-value-added is the elasticity times the change in log-price. Each $1 of carbon price corresponds to a 0.42% increase in electricity prices and a 0.86% increase in natural gas prices in CA in 2009, so a carbon price of $C has an impact on log-value-added of {[(electricity-elasticity)*ln(1 + (0.0042*C))] + [(gas-elasticity)*ln(1 + (0.0086*C))]}, shown here as a percentage change in value-added. The numbers are benchmarked to match the $10 carbon price impacts reported in Table 5. Comparisons of these estimated results with simulated results inside Census show very similar values for carbon prices ranging from $1 to $25.