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The Impact on U.S. Industries of Carbon Prices with Output-Based Rebates over Multiple Time Frames

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RESOURCES FOR THE FUTURE

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Abstract

The effects of a carbon price on U.S. industries are likely to change over time as firms and customers gradually adjust to new prices. The effects will also depend on the number of countries implementing the policy as well as offsetting policies to compensate losers. We examine the effects of a \$15/ton CO_2 price, including Waxman-Markey-type allocations to vulnerable industries, over four time horizons—the very short-, short-, medium-, and long-runs—distinguished by the ability of firms to raise output prices, change their input mix, and reallocate capital. We find that if firms cannot pass on higher costs, the loss in profits in a number of industries will indeed be large. When output prices can rise to reflect higher energy costs, the reduction in output and profits is substantially smaller. Over the medium- and long-terms, however, when more adjustments occur, the impact on output is more varied due to general equilibrium effects. The use of the H.R. 2454 rebates can substantially offset the output losses over all four time frames considered. We also consider competitiveness and leakage effects—changes in trade flows and changes in emissions in the rest of the world. We examine two measures of leakage: "trade-related" leakage that accounts for both the increased volume of net imports into the U.S. as well as the higher carbon intensity of these imports, and a broader leakage measure that includes the effect of increased fossil fuel consumption in countries not undertaking a carbon-pricing policy.

Key Words: carbon price, competitiveness, input-output analysis, output-based allocations, carbon leakage

JEL Classification Numbers: F14, D 21, D57, D58, H23

Contents

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I. Introduction

Pricing carbon emissions through an economy-wide cap-and-trade system or a tax not only will adversely affect electricity and primary energy producers, but also will hurt the competitive position of industries that consume large amounts of energy. Energy-intensive, trade-exposed (EITE) sectors, such as metals and chemicals, could be especially impacted under such a policy. This situation gives rise to two overarching concerns. First, some domestic industries will be disproportionately burdened if carbon-pricing policies affect their operations but not those of their international competitors. Second, some of the environmental benefits will be eroded if increases in U.S. manufacturing costs from uneven international carbon pricing cause economic activity and the corresponding emissions to "leak" to nations with weaker or no carbon-pricing policies.

Industry-level impacts are fundamentally tied to the carbon intensity of producers, the degree to which they can pass costs to consumers, and their ability to substitute away from carbon-intensive energy. The strength of competition from imports and consumers' ability to substitute other, less carbon-intensive alternatives for a given product also play crucial roles in determining the ultimate impacts on domestic production and employment.

While the most effective approach to reduce the disproportionate impacts of domestic carbon pricing is to ensure comparable action by other countries, recent experience on the international stage underscores the difficulty of reaching a broad-based international agreement in the near term. Absent such an agreement, the U.S. Congress has considered various legislative proposals to reduce the trade impacts of domestic carbon pricing, including the free allocation of emissions allowances to the most affected sectors. If these free allowances, or rebates, are updated on the basis of recent output levels as proscribed, for example, in the

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American Clean Energy and Security Act of 2009 (H.R. 2454), firms would be encouraged to maintain production levels in the face of policy-induced cost increases while sustaining incentives created by the emissions cap to reduce the carbon intensity of production. Importantly, the per-unit allowance allocation would not be based on the firm's emissions but on a sector-based intensity standard, thus creating incentives for within-sector market shares to shift toward firms with low emissions intensity.

Computable general equilibrium (CGE) models allow for the estimation of long-run industry-level and consumer welfare impacts of carbon-pricing policies after firms have adjusted by using new technologies and the market has established new import patterns. Many such analyses use a mobile-factor framework in which workers and producers are assumed to shift seamlessly from the taxed to the untaxed sectors. Such long-run analyses, however, fail to capture the short-run impacts of carbon-pricing policies. A steel mill faced with higher energy costs cannot immediately and without cost convert to more energy-efficient methods. If it leaves its output price unchanged, the higher input costs will lower profits. If it tries to raise prices to cover the higher costs, it will face lower sales. Stakeholders will likely oppose a carbon policy that does not fairly address these impacts.

Since the conditions facing firms and the available mitigation options will change over time, appropriate policies also must consider the temporal dimension of the impacts. Analyses using dynamic general equilibrium models do take some time-relevant adjustments into account. However, such models are highly aggregated and generally ignore potentially important differences among major energy-consuming sectors, such as cement, aluminum, chemicals, and others.

This paper advances the study of competitiveness issues by examining the impacts of both unilateral U.S. and uniform Annex I carbon-pricing policies. The analysis examines a highly disaggregated set of industries, accounting for time-relevant changes in the ability to fully adjust to policy realities and the free, output-based allowance allocations adopted in H.R. 2454 for EITE industries. The modeling also incorporates the special treatment of the refining sector as well as electricity and gas local distribution companies (LDCs) contained in this legislation. Other net revenues raised by the cap and trade system are returned to households, partially offsetting the higher prices. The analysis is based on an economy-wide carbon dioxide (CO_2) price of $15/ton, which is broadly consistent with projections of allowance prices under H.R. 2454 in the first half of the next decade (EIA 2009a; EPA 2009a). Building on the framework adopted in Ho et al. (2008), four time horizons are considered:

- the very short-run, where output prices cannot be changed but input prices rise and profits fall accordingly;

- the short-run, where output prices can rise to reflect the higher energy costs, with corresponding decline in sales as a result of product and/or import substitution;
- the medium-run, when in addition to the changes in output prices, the mix of inputs may change, but capital remains in place, and general equilibrium (i.e., economy-wide) effects are considered; and
- the long-run, or full general equilibrium analysis, when capital may be reallocated and replaced with more energy-efficient technologies.

We analyze both the first and second time horizons in a partial equilibrium framework with fixed input coefficients. The first horizon, without changes in output prices, involves no demand adjustments at all. While this may seem unrealistic, it produces the maximum possible impact on profits. The second horizon requires an estimate of the demand elasticity for each industry's output—i.e., the percentage change in sales resulting from a 1 percent increase in the industry's output price. We estimate these elasticities using a global general equilibrium model, which allows us to capture the effect of customers switching to other products, including substitution to similar imported commodities.

We analyze the third time horizon with a long-run CGE model based on the GTAP 7 database.[1] Such a model recognizes that the demand for steel, for example, depends not only on its price, but also on the price of plastics and other intermediate goods—indeed the price of everything in the economy. Higher energy prices raise the prices of steel and plastic while directly lowering the demand for both. In addition, a lower demand for plastic indirectly lowers the chemical industry's demand for steel. These general equilibrium effects are not considered in the first two time horizons. At the same time, the third, medium-run case continues to assume that capital is not mobile—i.e., it cannot move away from the now less profitable industries. Therefore, when sales fall because of higher costs being passed on as higher prices, profits will also fall, leading to a lower rate of return to capital.

The fourth time horizon, the full long-run analysis, allows for full capital mobility. Instead of industry-specific profit effects, the model shows the change in the economy-wide return to labor versus capital. The focus is on the long-run effects of carbon-pricing policies on consumption patterns—i.e., households and other components of final demand switching to less

[1] GTAP (Global Trade Analysis Project) is a global network of researchers who conduct quantitative analyses of international economic policies. The centerpiece of GTAP is a global database describing bilateral trade patterns, production, consumption, and intermediate use of commodities and services. See https://www.gtap.agecon.purdue.edu/ (accessed December 3, 2010).

energy-intensive products. This switch in final demand changes the structure of production and total energy consumption, but the long-run framework implies that returns to capital are equalized across industries. While the "long-run" may be defined in a variety of ways, our definition simply uses a one-period model in which the supply of capital is given exogenously. A model with intertemporal features that determines savings endogenously will identify an effect not considered here: how the total stock of capital responds to the changes in prices due to a carbon tax.

This framework allows us to capture the complex, often opposing adjustments occurring over time. On the one hand, producers of energy-intensive goods gradually can substitute toward cheaper, less carbon-intensive inputs, thereby lowering prices and increasing sales (see the supply curve shifting down, Fig A1 in Appendix A.1.1). On the other hand, the customers of such energy-intensive goods also are gradually substituting toward alternative inputs and capital (see the demand curve shifting down) and reducing the demands. The net effect of these long-run adjustments is not clear *a priori*. Indeed, our results show that both influences are at work.

H.R. 2454 provides allowance rebates to covered entities within an eligible sector for direct emissions from fossil fuel combustion as well as process-related sources. It also provides rebates for indirect emissions associated with the purchase of electricity. Eligible for rebate are six-digit North American Industry Classification System (NAICS) industries that have at least 5 percent energy or greenhouse gas (GHG) intensity and 15 percent trade intensity.[2] Additionally, other sectors that have an energy, or GHG, intensity larger than 20 percent are also deemed presumptively eligible. The list of 43 presumptively eligible industries, as determined by the U.S. Environmental Protection Agency (EPA), is incorporated into our calculations.[3] Refineries are not eligible for production rebates, although they are freely granted 2 percent of total allowances without regard to current output levels—i.e., via grandfathering.[4]

Provisions in H.R. 2454 would allocate about 30 percent of the allowances *gratis* to electricity LDCs and about 9 percent to natural gas LDCs. The legislation mandates that these allowances be used for the ratepayers' benefit, which is widely interpreted to include industrial

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[2] Energy (or GHG) intensity is measured by the value of energy costs (or carbon costs at a $20 per ton of CO_2 price) as a share of the total value of shipments in that sector. Trade intensity is calculated as the value of imports and exports as a share of the value of total production plus imports.

[3] Taking into account the potential to carry forward unused allowances from one year to the next, as authorized in H.R. 2454, the number of allowances available is estimated to exceed the 2006 emissions of the eligible industries through 2025 (EPA 2009b, 36).

[4] Small business refineries receive an additional 0.25 percent allocation not included in our estimates.

customers. Because indirect emissions from electricity consumption are an important component of total emissions of the eligible sectors, the LDC provisions are expected to mitigate a significant portion of the policy-induced costs to the eligible sectors. The allocations to natural gas LDCs are likely to have a smaller impact.[5]

Assumptions about climate policies adopted in other countries are clearly important in understanding competitiveness and leakage issues. To cover a range of possibilities, we consider both a unilateral U.S. effort and a multilateral case with comparable actions by key U.S. trading partners. The U.S. unilateral case is not representative of real-world conditions because some major U.S. trading partners already have adopted carbon-pricing policies. However, it is useful for comparative purposes. For the multilateral case, it is plausible to assume comparable actions when estimating competiveness impacts because roughly half of U.S. trade in energy-intensive goods involves the European Union, Canada, Australia, Japan, and New Zealand—nations that are reasonably expected to adopt carbon-pricing policies comparable to or even more stringent than those in the United States (EPA 2009b, 25). We present a limited set of results concerning emissions leakage; a more detailed description of the trade and leakage effects is given in Adkins et al. (forthcoming).

The focus in this paper is on a sequence of relatively transparent steps designed to estimate the impacts of carbon pricing with and without rebate policies over the different time horizons. Impacts are measured in terms of reduced output, profits, and trade effects. Following this introduction, Section II reviews a number of previous studies that have examined competitiveness issues at a detailed, industry-specific level. We particularly focus on the analyses that have incorporated output-based rebates mechanisms of the type contained in H.R. 2454. Section III describes the basic modeling approaches and data sources. For the more technically oriented reader, Appendices A and B provide further information on the models and data used, including the specific representation of H.R. 2454. Section IV presents an overview of cross-industry patterns of output, energy use, carbon intensity, and imports, as well as the industry-specific rebates contained in H.R. 2454. Section V describes the principal results for output and profits across multiple time horizons. Section VI addresses trade impacts. Section VII offers some overall conclusions.

[5] The natural gas LDC allocations only indirectly benefit the relatively small number of EITE industries that receive their gas from LDCs and whose emissions are not directly regulated under H.R. 2454.

II. Other Studies on Detailed Industry Impacts

The literature on industry impacts of carbon policies is based largely on simulation modeling, although a number of papers, including a recent one by Aldy and Pizer (2009), rely on statistical analysis. The simulation analyses include both short-term partial equilibrium assessments as well as long-term CGE modeling. Ho et al. (2008) review more than a dozen prior U.S. and European analyses and report a series of estimates based on an earlier version of the current modeling framework. With the exception of a single paper by Fischer and Fox (2007), however, none of the earlier literature estimates the *combined* effects of carbon pricing and output-based rebating. Starting in 2009, with the passage of H.R. 2454, a number of such analyses have been performed, albeit on a quite aggregated basis.

Fischer and Fox (2007) examine how the outcome of carbon policies is affected by alternative permit allocation mechanisms: auction, grandfathering, output-based allocation tied to emissions, and output-based allocation tied to value added. Using a model based on GTAP 6 data (2001 base year), they report impacts on 18 non-energy sectors and 5 energy sectors. In a policy scenario that reduces emissions by about 14 percent below baseline, they estimate a reduction in overall output on the order of 0.34 percent for the output-based allocations tied to emissions, rising to as much as 0.51 percent for the other mechanisms. Overall, output declines consistently for the alternative allocation mechanisms across all industries examined, except food products and services. The hardest-hit manufacturing industries are chemicals and iron and steel, at about 1 percent each. All other manufacturing industries report output declines that are generally 0.5 percent or less. Fischer and Fox (2007) report emissions leakage of 12–15 percent of total U.S. emissions reductions. The implied leakage rate for the energy-intensive industries is on the order of 40–45 percent.[6]

An assessment by the U.S. Energy Information Administration, using its NEMS model, finds that the rebate mechanisms contained in H.R. 2454 result in smaller-percentage output reductions for the EITEs than for the manufacturing sector as a whole (EIA 2009a). An analysis of H.R. 2454 by the EPA, using the ADAGE model, estimates that without the output-based rebate provisions, production in the energy-intensive manufacturing industries decreases by 0.3 percent in 2015 and by 0.7 percent in 2020 (EPA 2009a). With the output-based rebates, the EPA estimated that energy-intensive manufacturing output would *increase* by 0.04 percent in 2015 and fall by only 0.3 percent in 2020. Unfortunately, neither the EIA nor the EPA models disaggregate industry impacts to any significant extent.

[6] See also Fischer and Fox (2009).

An interagency report on the competitiveness impacts of H.R. 2454 (EPA 2009b) relies on an updated version of the Fischer–Fox GTAP-based model described above. Specifically, output-based rebates were modeled for 5 aggregated sectors, incorporating 37 of the 43 six-digit NAICS EITE industries deemed to be presumptively eligible for rebates. This procedure involves some approximations because not all six-digit industries within a modeled two-digit sector are presumptively eligible, but it represents a quite reasonable approach. Using somewhat more disaggregated industry classifications, we adopt a largely similar approach for modeling rebates in the present study.

The results of the interagency report—including those for output-based allocations at a rate equal to the average emissions intensity of an industry's production—are roughly consistent with the more aggregate findings from NEMS and ADAGE. For three of the five sectors analyzed in the interagency report, the combined effect of the direct allocations to EITEs, plus those to LDCs, offsets virtually all of the incremental costs associated with the carbon pricing. For two sectors—chemicals and plastics; pulp, paper, and print—the allocations actually yield a small net gain. In other words, they reduce production costs compared to the case without any carbon pricing. One issue of interest is the relative importance of the direct allocations to EITEs versus the LDC rebates. For the five relatively aggregated industry groups examined in the interagency report, the LDC rebates constitute a relatively small share of the total cost reductions compared to the consistently larger effect of the direct industry rebates.

The interagency report also considers the impacts of the rebate programs on trade flows giving rise to emissions leakage. Here, it is useful to recall the two main sources of emissions leakage: changes in trade flows and global substitutions in production processes associated with changing fuel and raw material prices induced by the domestic carbon policy. Fischer and Fox (2007, 2009) find the latter to be larger than the former. However, because trade flows are more readily influenced by policy measures than substitutions, and because they are an important proxy for domestic output and employment losses in the manufacturing-intensive states, the interagency report focuses solely on trade flows as the metric of impacts.[7]

Although the EU Emissions Trading Scheme (EU ETS) does not use an output-based rebate system, several recent studies have examined the possible impacts of such a mechanism on specific industries in the European Union. Demailly and Quirion (2006) find that if the EU

[7] The EPA's (2009b) interagency report actually was requested by five Senators from heavy industrial states. It is also noteworthy that while output-based rebates can stem the loss of net imports and, implicitly, the associated output and employment losses in the EITE industries, they are not an effective tool for addressing emissions leakage and other domestic impacts associated with changes in global fuel and materials prices.

cement producers received output-based allocations at a rate equal to 90 percent of the industry's historical emissions intensity, imports to the European Union would be insignificantly impacted under an EU cap-and-trade program, even if allowance prices reached as high as 50 Euros per ton of CO_2. Similarly, an analysis by the Carbon Trust (2008) found that output-based allocations in steel and other energy-intensive sectors could significantly reduce increases in imports that could otherwise result from the EU ETS.

III. Implementation: Data and Model Construction

The very-short-run and short-run cases examined in this paper rely on a fixed coefficient, input–output (I-O) model of the U.S. economy, disaggregated to the 52-sector level based on the NAICS. To represent the very short-run, where output prices cannot be changed but input prices rise and profits fall, the effect of a carbon tax is computed using a modification of the Leontief inverse.[8] Two cases are considered, one without the allowance rebates and one with them. The I-O data, which provide the dollar value for industry output and intermediate inputs used by a detailed set of U.S. industries, are based on the 2006 I-O tables supplemented by details from the 2002 benchmark I-O tables (see Appendix B). We use 2006 data because it is the most recent year of the EIA's Manufacturing Energy Consumption Survey, which gives the energy consumption data for a detailed set of manufacturing industries, including fossil fuel and electricity use, distinguished by combustion and non-fuel use (EIA 2006b).

For some non-manufacturing sectors, we rely on energy-use data from the *Annual Energy Review* (EIA 2006a). For consistency, we reconcile these energy data with the national totals and with the I-O value estimates to compute the carbon emissions from combustion and electricity use in each industry. *Emissions of Greenhouse Gases in the United States 2008* (EIA 2009b) provides a detailed picture of the emissions from direct fuel consumption and process emissions. The three main sources of process emissions are cement production, limestone consumption, and natural gas production, together accounting for 87 percent of the total 104 million tons of CO_2 from process emissions in 2008.[9] While a small portion of total U.S. emissions, they represent a significant proportion of the total emissions of these three industries.

[8] Our methodology is described in detail in Appendix A. The carbon embodied in a unit of output is given in equation A17. This modifies the standard Leontief formula to take into account the fact that some energy inputs are feedstock and therefore not combusted. The effect of the carbon price on commodity prices is then given by equation A19. These changes in prices raise the cost of production; equation A34 gives the effect of the higher costs, less any subsidies, on the output price.

[9] See Appendix B for complete data description. The process emissions are given in Table 15 of EIA 2009b.

For the short-run analysis, where output prices can rise to reflect higher energy costs, with corresponding declines in sales as a result of product and/or import substitution, the I-O model is supplemented with an elasticity of demand for industry output. In the absence of comprehensive, consistent estimates of such elasticities for all industries, we calculate the elasticities using the CGE model, described below.

To estimate the demand elasticity for industry *j*, we simulate a small tax on the output of *j* and record the effect on its sales. For energy-producing industries, such as coal and oil, we apply the same tax to imports because the goal is to price the consumption of fossil fuels. Estimating the demand curve for coal is a more delicate exercise. A price of $15 per ton of CO_2 would almost double the price of coal at the mine mouth. As a result, we need to estimate the demand curve over a large range of prices and should not expect a linear assumption to be valid for the whole range. In this case, we simulate the demand elasticity by applying a 75 percent tax on coal. Since the CGE model is more aggregated than our I-O model, the elasticity estimated, for example, for chemicals, is applied to all six sub-industries in the chemicals group. This simulation procedure is applied to all industries except petroleum refining, for which we impose a short-run demand elasticity that is smaller than that generated with the CGE model, based on the work of Hughes et al. (2006).

The proposed bills have provisions to return the revenue from the sales of permits back to households, that is, the revenue left over after giving the rebates to the EITE industries. Economists debate how households dispose of such transfers. Are they regarded as temporary and thus mostly saved, or are they regarded as permanent allowing a higher level of consumption permanently? If the latter, do they change the spending habits within our "short-run" horizon? Since the carbon price plan is a long-run plan with carbon prices and transfers that last many years into the future, we take the simplest approach and assume that all of the transfers will be spent in the short-run. For the short-run horizon we use a simple "partial equilibrium" approach, and as explained above, estimate the change in sales of each commodity using the elasticities estimated. We do not aim for general equilibrium completeness here. In that spirit, we estimate the household consumption change due to the transfers as a simple scaling of current expenditures, in proportion to the total transfers.[10]

In the I-O framework, the value of output for each industry is equal to the sum of the intermediate inputs, compensation of employees, indirect business taxes, and other value

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[10] In terms of the diagram in the Appendix, Figure A2, we shift the demand curve out, at the same time that the carbon price shifts the supply curve back.

added, which is often referred to as capital compensation.[11] We use the term "profits" to refer to this other value added; it includes the conventional pre-tax profits and the value of depreciation.

To analyze the medium- and long-run, we use a multi-country CGE model with global coverage that allows us to simulate both the input substitution and trade effects. For the long-run scenario, we simulate a carbon tax and use the model to estimate the effects on the outputs and inputs of each industry, allowing for a full set of substitutions within each region. For the medium term, capital is assumed to be fixed and cannot be re-allocated among industries. In all cases, factors are assumed to not move across borders.

The CGE model is based on the GTAP 7 database (2004 base year) and is an updated version of Adkins and Garbaccio (2007) and identifies 8 regions and 29 sectors. The regions are the United States, Canada, Mexico, China, India, the rest of Annex I, oil-exporting countries, and the rest of the world. The 29 sectors include 15 manufacturing sectors and 6 energy sectors: coal, oil mining, gas mining, gas distribution, petroleum and coal products, and electricity. The production functions are constant elasticity of substitution, where capital and labor form a "value-added" aggregate input, and there is substitution between value-added inputs and an energy bundle. Imports are imperfect substitutes for domestic varieties. The labor supply is elastic for all but the lowest income regions (China, India, and rest of the world). Among the simulation outputs, the model can calculate the effects of the CO_2 tax on industry-specific exports and imports, where the tax is defined as a levy on both domestic fuel producers and importers.

For all four horizons, we consider two policies, a carbon tax only and a carbon tax plus output-based rebates. The subsidies are described in Section IV below. In the model simulations, these subsidies are put on the industry output prices so that producers receive more than what consumers pay. Although the legislation provides for a gradual phase-out of these subsidies, in our simulation, we consider only the impact of the initial, maximum level of subsidies. As a result, our "long-run" scenario should not be interpreted as the simulated effect of the legislation in year 2030 but as an indication of the effects of capital adjustment to the subsidies.

The issue of how the new revenue from a carbon tax, or sales of permits, is used is an important one that is addressed in the literature on tax distortion and tax interaction effects.

[11] This "other value added," described in detail in Appendix B, includes the value added of proprietorships, which compensates for both capital and labor of the proprietors.

Revenues that are recycled back through reductions in other tax rates will reduce the tax distortions there, revenues that are recycled as lump-sum transfers will not. Revenues that are used for new government spending may provide new public goods. For our analysis of the longer horizons we use the option that is clearest to analyze—a reduction in tax rates on labor income. We believe this is also the more realistic option. That is, in our simulations, any new revenue that is not rebated back as output subsidies will be used to reduce the labor tax, keeping government expenditures and deficits the same as the base case. For the short-run (no substitution) horizon, these revenues are simply used to dampen the fall in real consumption expenditures. [12]

IV. Industry Patterns and Rebates under H.R. 2454

Energy Consumption Patterns and Carbon Intensity

We begin this section by describing the energy consumption patterns and carbon content of the 52 industries considered in the short-run analyses. Tables 1–3 present a summary of these industries' energy consumption, expressed as energy costs as a share of total costs for electricity, fossil fuel (combusted portion only), and total energy, including non-combustion use of fossil fuels. Total costs are defined as the value of all inputs for industry *j*, including capital input, and the total is equal to the value of industry output (at the seller's price before taxes on production).

As shown in column 3 of Table 1, the contribution of energy costs, including feedstocks, to total costs varies widely across the different manufacturing industries, ranging from 69 percent in the petroleum industry to less than 1 percent in miscellaneous manufacturing, computer and electrical equipment, and apparel. For the non-manufacturing sectors, a similarly wide range exists, from a high of almost 49 percent in gas utilities to about 0.4 percent in finance and insurance. Of the 33 manufacturing industries, 22 have energy costs exceeding 6 percent of total costs. Of the 19 non-manufacturing industries, 8 have energy costs exceeding 6 percent of total costs. Even when energy costs are restricted to the combusted portion, as shown in column 2 of Table 1, the cost shares are as high as 23.6 percent in the fertilizers industry.

Within the manufacturing sector, the use of specific fuels also varies greatly. As can be computed from columns 2 and 3 in Table 1, more than 60 percent of total energy costs are

[12] The alternative assumption of lump sum recycling in the medium- and long-run analyses has a negligible effect on industry results.

associated with direct fuel combustion in a number of industries: pulp mills, petrochemical manufacturing, other basic organic chemical manufacturing, glass, lime and gypsum, and other nonmetallic minerals. Electricity accounts for more than 60 percent of total energy costs for other industries, including textiles, apparel, inorganic chemical manufacturing, alumina refining and primary aluminum production, ferrous metals, machinery, computer and electrical equipment, motor vehicles, other transportation equipment and miscellaneous manufacturing.

Outside of manufacturing, the gas utilities sector has the highest energy cost share at 48.9 percent. This is followed by air transportation at 21.3 percent, most of which is direct fuel combustion. Electricity generation (private and government utilities) is at 17.7 percent, followed by other mining activities at 7.4 percent.

Table 2 displays the value of industry output for the 52 industries along with the energy consumption information, expressed as a physical quantity for the 6 fuels included in the model (with the largest manufacturing consumers listed here in parentheses): tons of coal (iron and steel), barrels of crude oil (refining), liquid petroleum gas, or LPG (refining), other petroleum (petrochemical manufacturing), cubic feet of natural gas (refining), and kilowatt-hours of electricity (other chemicals and plastics). Not surprisingly, coal and natural gas use by electric utilities is far greater than that of even the largest manufacturing consumers. Similarly, use of non-LPG petroleum as well as electricity by the air transport, real estate, and rental industries far exceeds that of the largest manufacturing consumers of those fuels.

Table 3 presents the CO_2 emissions (expressed in thousandmetric tons) for direct combustion, electricity consumption, and process emissions, as well as total CO_2 content per million dollars of output—i.e., total CO_2 intensity. Note that more than half the total emissions are process-related from cement and from lime and gypsum, the two most CO_2-intensive manufacturing industries. Fertilizer, the third most CO_2-intensive industry, is dominated by direct combustion (mostly of natural gas), while in alumina refining and primary aluminum, the fourth most CO_2-intensive industry, about 80 percent of emissions are derived from electricity consumption.[13]

Import Exposure

While the vulnerability of domestic producers to import competition is not necessarily related to the level of import penetration, a high import share does indicate a potential for such

[13] A detailed description of the data and calculations is given in Appendix B. The CO_2 content of the electricity consumed by industry is derived from state-specific data on electricity production and industry output. Thus, the aluminum produced in states with more zero-emission hydropower is reflected in this calculation.

competition. The last column of Table 1 displays the import share of total U.S. consumption by value. The contribution of imports to total supply of manufactures in the U.S. market also varies greatly by industry, ranging from 87 percent for apparel and 64 percent for computer and electrical equipment to zero for nonferrous metal foundries. In the results presented below, the vulnerability to imports or international leakage associated with an increase in the domestic CO_2 price depends on the import substitution elasticity (as embodied in the CGE model) and the import share.

Output-Based Rebates under H.R. 2454

As discussed in greater detail in Appendix A.2, H.R. 2454 provides for rebates to energy-intensive, trade-exposed industries based on their historical CO_2 emissions. Table 4a displays our estimates of the value of these allocations to EITE industries, and the implied subsidy rates, based on our 52-industry disaggregation. While the refining industry is not technically eligible for the output-based rebates, the value of the grandfathered rebates granted to them also is displayed in Table 4a.[14] Of the 33 manufacturing industries, 21 are eligible for at least some rebates, while the remaining 12 industries receive no rebates at all. Firms within the eligible industries will be allocated quotas based on their output. The top rebate recipients are refiners ($2.02 billion), iron and steel mills ($943 million), and other basic organic chemical manufacturing ($779 million). We compute the subsidy rate as the ratio of the industry rebate value to the industry output value.[15] These subsidy rates vary widely among the various sectors, ranging from a low of 0.002 percent for food manufacturing to a high of 4.47 percent for cement. The LDC allocations for electric and gas utilities are also translated into output subsidy rates.

The last column of Table 4a, the qualifying industry share, reflects the portion of industry output presumptively eligible for rebates under H.R. 2454. Thus, paper mills, pulp mills, and 12 other industries, all identified at the six-digit NAICS level, qualify for rebates on 100 percent of their output. Since fertilizer, chemicals and plastics, and six other industries are not entirely comprised of presumptively eligible six-digit NAICS industries, their qualifying share is less than 100 percent.

Comparable calculations for the industry definitions used in our 29-sector medium- and long-run analyses are displayed in Table 4b, which also includes a concordance between the

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[14] H.R. 2454 grants 2.25 percent of the total allowances to the refining sector; with our industry disaggregation this is allocated to "Refining-LPG" ($114.1 million) and "Refining-Other" ($1,905.8 million).

[15] See equation A49 in Appendix A.

29- and 52-sector aggregations. Of the 15 manufacturing industries represented in the CGE model, nine are eligible for subsidies (including the allocation to refining). We see that the subsidy rate for the now more aggregated chemicals, rubber, and plastics sector is only 0.25 percent, while Table 4a indicates that the component sub-sectors range from 1.23 percent for petrochemicals to 0.02 percent for other chemicals and plastics. Cement, which had the highest subsidy rate at 4.47 percent in Table 4a, is subsumed within nonmetallic minerals in Table 4b, which receives a subsidy of 0.5 percent.

V. Effects of a Carbon Tax over Different Time Horizons

This section presents the results of our four different modeling frameworks. The most comprehensive results are available for industrial output, while industry-specific estimates for profits and trade effects are presented for only some modeling horizons. To illustrate the effects of an economy-wide carbon-pricing policy, we simulate the effects of a carbon tax of $15/ton CO_2 (2006$) with and without accompanying output-based rebates for EITE as well as those for electricity and gas LDCs and petroleum refining.[16]

Effects on Industry Prices: Very-Short-Run Horizon

Table 5 displays the effects of a $15/ton CO_2 tax on industry output prices with and without the output-based rebates, over the very-short-run time horizon.[17] As noted, this scenario is a hypothetical, worst-case assessment because it assumes that producers cannot raise prices, adjust output, change their input mix, or adopt new technologies in response to higher costs. Nonetheless, recognizing that the carbon tax (net of the rebates) will raise the price of all intermediate inputs, we do include this increase in industry prices on the input side. At the same time, when calculating the effect on profits in the very short-run, output prices are assumed to remain unchanged. Thus, there is an inherent inconsistency in the very short run analysis: firms pay more for their inputs but are unable to pass along the added costs to their customers. The results in Table 5 are thus valid taken one industry at a time, they cannot be regarded as applicable simultaneously. The value of the exercise is in the (subsequent) comparison with the short run results, where we highlight the importance of output price increases as a means of offsetting reductions in profits.

[16] For the very-short-run and short-run time horizons, we compute the effects on costs by using equation A21 for each of the 52 industries, as shown in Appendix A.

[17]The change in industry prices is computed using equation A34.

For most manufacturing industries, industry prices are estimated to increase by less than 2 percent even without the rebates. For some industries, however, the price increases are larger: refining-lpg prices are estimated to rise the most (22.4 percent), followed by other refining (9.8 percent) and cement (5.7 percent).[18]

With the subsidies, the estimated price increases are smaller but not uniformly so. While the rebates only slightly reduce the price increases for refining because these goods bear a direct tax on carbon, they almost completely eliminate other price increases. Other large beneficiaries (in percentage terms) from the H.R. 2454 industry rebates include pulp mills, paper mills, glass containers, iron and steel mills, and alumina refining. The only two non-manufacturing sectors substantially benefiting from the H.R. 2454 industry rebate provisions are the electric and gas utilities, where the rebates suppress approximately 80–90 percent of the price increases that would occur otherwise .

Effects on Costs: Very-Short-Run Horizon

Given the tax-induced changes in industrial prices noted above, we now describe the industry-specific effects on costs. The estimated percentage changes in total unit costs, without the subsidies, are displayed in the first column of Table 6, while the remaining columns give the contributions to this total from changes in fuel prices (direct combustion), electricity prices, and prices of non-energy inputs.

The most heavily impacted sector is electricity generation, where costs rise by 9 percent. Three of the 33 manufacturing sectors—cement, other basic organic chemical manufacturing, and lime and gypsum—are estimated to face cost increases exceeding 3 percent. The following eight manufacturing sectors face cost increases between 2 and 3 percent: paperboard mills, petrochemical manufacturing, plastics and material resins, artificial and synthetic fibers and filaments, fertilizers, glass containers, iron and steel mills, and alumina refining. We emphasize that these are the effects of a \$15/ton CO_2 tax. For a \$60/ton tax, costs would be larger by a factor of four (in percentage terms).

Table 7 presents a similar breakdown of cost impacts with the inclusion of the H.R. 2454 rebates. Not surprisingly, the overall impacts of the policy are lessened. Only the cement sector has cost impacts greater than 3 percent. Three sectors—other basic organic chemicals, lime and gypsum, and petrochemicals—have cost impacts between 2 and 3 percent. For those

[18] The price changes in Table 5 are changes in industry prices, as opposed to commodity prices. This distinction is described in Appendix A but is not significant for our purposes here. Commodity price effects are available on request.

sectors having a 1–2 percent increase under a carbon-pricing policy without rebates, the introduction of rebates appears to have only a small effect on costs. Eleven manufacturing sectors experience cost impacts of 1–2 percent when rebates are present compared to twelve without the rebates. In the non-manufacturing sectors, we see no significant changes with the introduction of rebates. For electric and gas utilities, the cost impacts of more expensive coal and gas are essentially the same because the rebates subsidize the output of these utilities, not the inputs.

Of particular interest is the pattern of differences in unit costs with and without the rebates. For example, glass containers, mineral wool, aluminum, and other primary metals experience net cost increases that are 50–70 percent smaller with the rebates. This is due to the large subsidy for electricity prices, which is an important input in metals production. In the case of aluminum, the change in electricity costs raises total costs by 1.58 percent in the no-subsidy case but only by 0.3 percent in the rebate case.

Effects on Output and Profits: Short-Run versus the Very-Short-Run

In contrast to the very-short-run, where there is an inherent inconsistency between the individual sector results and those for the full set of industries, in the short-run horizon the treatment of input and output prices is fully consistent, as we assume that producers raise prices to cover the higher unit costs, with resulting reductions in sales and output as customers switch to alternative goods or imports.[19] As expected, the extent of import substitution depends critically on the assumptions made about the carbon-pricing policies of other countries. We consider two polar cases. The first assumes that the United States takes unilateral action and that none of our trading partners, including the European Union, adopt comparable policies. While this is an unlikely outcome, it is instructive because for a given time frame, it provides an upper bound on the impacts on U.S. industries. Much smaller losses in sales and output are seen in the second case, where it is assumed that all Annex I nations adopt a carbon-pricing scheme comparable to H.R. 2454.

Table 8 displays the short-run changes in output with full revenue recycling both with and without the H.R. 2454 industry rebates. Table 8 also displays alternative assumptions of unilateral U.S. carbon pricing and Annex I-wide actions. In contrast to the very short-run, when industry output is assumed fixed, we observe substantial output reductions in the short-run, especially with unilateral action and no rebates. As shown in column 1, the sectors that incur

[19] As noted in Section III, to determine the sales response, we estimated the elasticity of demand for each industry using the 29-sector, multi-region global model. These elasticities are given in Table B1.

the biggest output losses in this case are other basic organic chemicals (4.6 percent), alumina refining (4.1 percent) and cement (4.1 percent). Experiencing losses between 3–4 percent are three other sectors: fertilizers, plastics and material resins and petrochemical manufacturing. The relatively large output declines in these sectors arise from the combined effects of large cost increases without the H.R. 2454 industry rebates and the relatively high demand elasticities of these industries under unilateral action. Some service industries gain as a result of the revenue recycled back to households.

With the H.R. 2454 industry rebates, but still assuming unilateral U.S. action, output losses are generally lower. As shown in Table 8, column 3, the rebates are particularly beneficial to cement, alumina refining and primary aluminum, and glass containers. The output loss for cement is reduced close to zero. Glass containers and aluminum refining appear to gain slightly. Other sectors that see significantly smaller declines in output (in percentage terms) because of the rebates are iron and steel, paper mills, inorganic chemicals, mineral wool, and pulp mills. The service industries do not fare as well when the H.R. 2454 industry rebates are included, as the amount recycled back to households is halved, limiting the amount of expenditure switching from carbon intensive commodities to cleaner ones.

With the assumption of a common Annex I carbon-pricing regime, the output losses are reduced further, in some cases dramatically so. For example, the cement industry losses are reduced from 4.6 to 1.8 percent without the H.R. 2454 industry rebates. With H.R. 2454 industry rebates, sectors that see their output losses reduced to 0.1 percent or less include pulp mills, paper mills, cement, mineral wool, and iron and steel. In percentage terms, some of the biggest improvements occur in the chemicals and metals industries, reflecting the importance of competition from Annex I trade in these sectors. Glass containers and the aluminum refining industry see modest gains in output under a multilateral policy with rebates.

Although the output losses in the non-manufacturing sectors are generally smaller when multilateral action is considered, the pattern of responses to the H.R. 2454 industry rebates with multilateral action is similar for the non-manufacturing and manufacturing sectors. As expected, for the non-manufacturing sectors, coal and other fuel-producing industries see the biggest increase in prices (to the buyer, not the producer) associated with a unilateral, tax-only policy, and the biggest declines in sales. While the coal mining output loss is not significantly affected by the multilateral-policy assumption, the principal non-manufacturing gainers from the rebate policy are electric and gas utilities, as the LDC rebates substantially cushion the drop in demand that would otherwise occur.

The effect of the carbon-pricing policies on profits is particularly pronounced. Tables 9 and 10 display the no-rebate and the rebate cases, respectively. Recall that we define profits as the gross return to capital—i.e. sales revenue plus rebates (if applicable) minus purchases of intermediate inputs and labor costs. For comparison purposes, we also present the results for the very-short-run analysis, where we assumed that sellers could not raise prices to cover higher costs.

Overall, while most U.S. industries benefit from a uniform carbon price applied in all Annex I countries, the gains are greatest in those sectors with less elastic demands, and more so for sectors receiving substantial rebates. Starting with the no-rebate case (Table 9), we see often-dramatic declines in adverse profit impacts across all industries as we move from the very–short-run, to the short-run with unilateral U.S. action, to the short-run with Annex I–wide policies. For example, other basic organic chemicals experiences a decline in profits of 84.3 percent in the very short-run when the output price is fixed vs. a 5.0 percent decline in the short-run when they are free to raise output prices (assuming unilateral U.S. action). With Annex I–wide policies the reduction in profits is only 1.3 percent. Other industries see generally similar patterns. Overall, 25 of the 33 manufacturing industries and 5 of the 19 non-manufacturing industries experience declines in profits of less than 1 percent with Annex I–wide policies but no rebates. Of the remaining 14 non-manufacturing industries, 9 actually experience small profit increases.

As shown in Table 10, roughly comparable patterns apply when the H.R. 2454 industry rebates are in place. With the rebates and unilateral U.S. action, the other basic organic chemicals sector experiences profit declines of 45.9 percent in the very short-run, dropping to 2.7 in the short-run. If Annex I–wide policies are assumed, the profit decline is only 0.9 percent. Note that in the multilateral case, all but 2 of the 33 manufacturing industries experience declines in profits of less than 1 percent.

Among the non-manufacturing sectors, most experience declines in profits of less than 1 percent in the short-run with or without the allocations to the EITE industries. The principal exceptions are the fossil fuel–producing sectors. Here, the very-short-run assumption of no change in output means a smaller loss compared to the short-run assumption, when the consumers of fossil fuels react to the carbon tax by buying less fuel. In the case of coal mining, in the very-short-run horizon, we see a 2.1 percent fall in profits without rebates. When we account for the reduction in coal use because of the higher prices, however, profits fall by 25.7 percent in the unilateral case and 25.8 with an Annex I–wide carbon policy. Similar, albeit less dramatic patterns apply to oil and gas mining. The non-manufacturing industries experiencing a profit loss in excess of 1 percent in the short-run with the rebates in place are oil mining and gas mining, at 1.4 percent. An Annex I-wide carbon policy tends to modestly increase the profit losses for the oil and gas mining industries to 2.7 percent.

A number of other interesting patterns are visible in the non-manufacturing sectors. Air transportation faces the largest profit decline in the very short-run without the rebates, followed by the electric utilities industry. With the LDC rebates, losses to the electric utilities industry are almost completely mitigated. In the very short-run, the profit impacts to the gas distribution industry are small in the tax-only case. While the rebates lead to a substantial windfall in the very short-run, the windfall disappears when customers reduce their demands in response to higher prices in the short-run case. Air transportation is virtually unaffected by the rebates because of the modest use of electricity in that sector, but the adverse effects of a carbon price dramatically decrease as the added costs of carbon pricing are passed forward to end users.

Not surprisingly, the variation in output and profit impacts is sensitive to the breadth of the industrial categories considered. Within the chemicals group (NAICS 325), the very-short-run change in profits (without rebates) varies by a factor of 20, from 4.0 percent in other chemicals and plastics to 84.3 percent in other basic inorganic chemicals. If we had averaged over the whole group, the low estimate for other chemicals and plastics would have dominated the results (see the output values in Table 2.) In earlier work, Morgenstern et al. (2004) found that sub-industry impacts estimated at a four-digit classification level (based on the Standard Industrial Classification) can be an order of magnitude larger those estimated at the two-digit level. As discussed in Appendix B, the availability of consistent information to serve as inputs to the relevant models dictated our choice of aggregation level.

A further issue involves the scaling of results to different CO_2 price levels. Since the calculations for both the very-short-run and short-run analyses are based on relatively simple linear models, they can be readily scaled up or down to reflect different assumptions about CO_2 prices. In contrast, in the medium- and long-run horizons examined below, the model explicitly involves nonlinearities that cannot be so readily scaled. At the same time, even for the short-run case, one has to be careful about considering large CO_2 price changes, since the calculated demand elasticities, which are based on the multi-sector global CGE model, are strictly intended for marginal analysis. How the system would respond to large increases in prices is an issue that must be carefully considered.

Effects on Output over the Four Time Horizons

We next turn to comparing the shorter-run effects to those over the longer run. As noted in Section III, the global CGE model used to consider the longer horizons only identifies three digit–level industries for manufacturing, for a total of 29 sectors, compared to the 52 sectors just discussed. In order to compare them to the global model estimates, we first aggregate the results for the 52 industries in Tables 9 and 10 to the same 29 industrial categories using output values as weights (see Table 4b for a concordance between the 29-sector and 52-sector aggregations). Table 11 displays the effects of a \$15/ton CO_2 tax without the H.R. 2454 industry rebates on output across the three modeling horizons. Comparable results with the H.R. 2454 industry rebates are displayed in Table 12.

Recall that in the medium term, producers may substitute among all inputs except capital. Thus, firms may substitute labor for energy or gas for coal. However, only in the long-run can firms move capital to other sectors and substitute it for energy or labor. Furthermore, in the general equilibrium framework, both producers and purchasers are changing their behavior, and these may have opposing effects on output over time. On the one hand, producers are substituting inputs to reduce costs and hence prices. Over time, lower prices should help raise sales and output. On the other hand, customers are making substitutions to avoid the higher prices for carbon-intensive products and thus reducing their demands and the corresponding sale of these products.

Looking across the columns of Table 11, which excludes the H.R. 2454 industry rebates but includes alternative assumptions about unilateral U.S. vs. Annex I–wide carbon-pricing policies, we see the competing effects at work. Turning first to the unilateral policy case, of the 13 manufacturing sectors that experience output declines in the short-run, the output declines in the medium-run are smaller for 11 of them. For example, in chemicals, output losses of 1.87 percent are reduced to 1.86 percent. In non-metal mineral products, the output losses decline from 1.46 to 1.13 percent. The exceptions are petroleum products and fabricated metal products, which see a small increase in the output loss. For the special case of petroleum products, we use a smaller short-run elasticity of demand compared to the parameters in the global model. Thus output falls in the medium-run by 6.3 percent compared to 0.3 percent in the short-run. The two industries that experience output gains in the short-run—food, beverages, and tobacco and wearing apparel—also experience a worsening in the medium-run.

For the non-manufacturing sectors, the medium-run output loss is larger in 5 of the 9 industries that experience output declines in the short-run: agriculture, other minerals, gas utilities, construction, and transportation. Four industries had gains in the unilateral, short-run case, including trade, communication, finance and insurance, and services. For all of these industries, the gains were lower in the medium-run compared to the short-run. The short-run sees a sharp reduction in the use of coal and a smaller reduction in the use of gas. Allowing for input substitution over time seems to encourage a bigger switch to non-energy inputs, away from gas. The transportation sector's ability to substitute toward non-carbon-intensive inputs seems limited and is dominated by the effect of customers shifting their purchases away from expensive transportation. Thus, the medium-run fall in output is considerably larger than it is in the short-run: 1.63 percent compared to 0.15 percent.

In contrast to the medium-run, the long-run sees a substitution of capital for other inputs. Of the 14 manufacturing sectors that experience output declines in the medium-run, 10 have output declines that are larger in the long-run, although for the most part the changes are relatively small. For example, the output decline in non-metal mineral products grows from 1.13 percent in the medium term to 1.41 percent in the long term. On the other hand, in the machinery sector, the decline shrinks from 0.27 to 0.17 percent. Three industries see declines in the modest output losses they experience in the medium-run when moving to the long-run. Wearing apparel and other manufacturing experience slight output gains.

Comparing the multilateral policy case with the unilateral policy case, the most notable differences are the responses of the manufacturing sectors in the medium-run versus the short-run. In the unilateral case, all but two manufacturing sectors show a diminished output loss. In the multilateral case, the 13 industries that see output declines in the short-run are the same ones as in the unilateral case. However, only four have less pronounced output declines in the medium-run. For nine of them, the fall in output is bigger in the medium-run; for example, the fall in chemical output goes from 0.38 in the short-run to 1.25 percent in the medium-run. We emphasize, however, that the relative change is different from the absolute change. For a given time horizon, the multilateral policy has a smaller impact on output than the unilateral case in almost all industries. It is the relative change that can go in opposite directions. Similar outcomes occur for the multilateral and unilateral cases when moving from the medium- to the long-run.. In the multilateral policy case, 12 of the 15 manufacturing industries that experience output declines in the medium-run see larger declines in the long-run, compared to 10 out of 14 in the unilateral case.

Not surprisingly, the pattern of changes in the rebate case (Table 12) is generally similar to the no-rebate results, although not entirely so. As in the no-subsidy, unilateral policy case, the changes in manufacturing output in the medium-run are generally smaller than in the short-run with the tax and rebate policy. Only in nonferrous primary metals, petroleum, chemicals, and fabricated metals are the medium-run losses (slightly) larger than the short-run losses (with larger losses in petroleum products being due to the choice of short-run elasticity as explained above). Going from the medium to long-run in the unilateral case, 7 of the 15 manufacturing sectors show slightly larger long-run output reductions compared to the medium-run.

Importantly, the eight sectors that receive more significant subsidies in Table 4b (ranging from 0.17 percent to 7.23 percent of the value of industry output)—all of which experience output declines in the six no-subsidy cases presented in Table 11—experience lower output declines for the corresponding six subsidy cases in Table 12. The sole exceptions are petroleum and coal products, which shows slightly larger output losses in the two short-run subsidy cases (-0.59 versus -0.33 for the unilateral case and -0.67 versus -0.43 for the multilateral case), and paper and chemicals in the short-run multilateral case. Not surprisingly, this is not the case for the sectors that do not receive subsidies (or receive subsidies at rates that are very close to zero), since the subsidies will shift the relative burden of reductions onto non-subsidized sectors.

VI. Trade and Leakage

A U.S. carbon-pricing policy will not only affect firms' costs and corresponding prices, output, and short-run profits, but will also impact international trade and emissions leakage. Beyond the direct trade effects, changes in domestic and world prices due to carbon-pricing policies will further alter the pattern of exports and imports which, in turn, implies changes in the location of production and the possibility of additional emissions leakage. In Adkins et al. (forthcoming), we provide a detailed description of the methodology to estimate changes in trade and emissions leakage as well as a full set of findings; here we summarize some key results.

In the face of a U.S. or Annex I carbon pricing policy, total CO_2 emissions in countries without such policies can increase for two reasons: 1) the United States or Annex I countries increase net imports of carbon-intensive goods from countries without carbon pricing policies as these goods become more costly to produce in the United States or Annex I countries, and 2) fossil fuel consumption increases in non-policy countries as world energy prices fall in response to U.S. or Annex I demand reductions. The latter increase in fossil fuel consumption will induce higher carbon intensities in both production and household consumption in non-policy countries. Thus, emissions leakage due to changes in net imports into countries with carbon pricing has two components—changes in the quantity of net imports and differences in the carbon intensities of production. The following discussion first considers trade impacts, and then turns to the consideration of price-induced increases in fossil fuel intensity in response to U.S. or Annex I demand reductions.

Trade Impacts

In previous sections, we estimate the changes in domestic output or production induced by the imposition of a domestic carbon pricing regime with and without accompanying output-based rebates of the type incorporated in H.R. 2454. Yet these production changes do not necessarily impact domestic consumption on a one-for-one basis because some of the output reductions may be made up abroad. Specifically, the change in domestic production is equal to the changes in consumption plus exports minus imports (ignoring changes in inventories, which are not modeled; see equation A62 in Appendix A). The results without the rebates for the medium and long-run are displayed in Tables 13 and 13b. The results with the rebates are in Tables 14 and 14b.

The first columns of Tables 13 and 14 are the base-year (2004) values for domestic output for the 29 commodities in the CGE model. In Tables 13a and 13b, the columns marked "Change in Output" are the effect on U.S. output of a $15/ton CO_2 price applied unilaterally within the U.S. only and multilaterally within Annex I countries. In addition to the carbon pricing policy, Tables 14a and 14b include the impacts of the Waxman-Markey allocations (listed in Table 4b) applied in the U.S. The three columns under "Contribution" show how changes in consumption, exports, and imports contribute to this output change. We see a varied set of trade impacts across the different sectors.

For example, in Table 13a for a unilateral U.S. policy and no rebates, the output of the chemicals, rubber, and plastics sector falls by 1.86 percent. Of that amount, the fall in domestic consumption contributes 0.65 percentage points; the fall in exports, 0.85 points; and the increase in imports, 0.36 points (i.e., -1.86 = (-0.65) + (-0.86) – (0.36)). The fall in output does not lead to a corresponding fall in consumption, as imports increase to replace about 19 percent of the output reduction (i.e., (-0.36)/(-1.87)), and the diversion of exports to domestic use replaces another 45 percent (i.e., (-0.85)/(-1.87)). Thus, changes in net imports make up 65 percent (= (-0.86 -0.36)/(-1.86)) of the output decline. We label this the "trade impact" (equation A63b in Appendix A).[20] Other energy-intensive industries (e.g., non-metallic mineral products, ferrous metals) also experience large changes in imports and exports. In less energy-intensive industries, the output reductions are generally smaller, but the trade impacts are quite varied. For example, the fall in output of transportation equipment is 0.23 percent, while the trade impact is 23 percent; in the case of wood products the trade impact is even a small negative value since imports fall.

With multilateral action, recall from Table 11 that changes in output for the energy-intensive industries are uniformly lower than they are with a unilateral policy. Tables 13a and 13b show that with multilateral action, changes in exports and imports are also almost always smaller than they are with a unilateral policy. For less energy-intensive industries, output losses as well as changes in exports and imports in the multilateral case are generally similar to those estimated with the unilateral policy. Thus, while the multilateral adoption of carbon-pricing policies reduces the overall reduction in domestic output compared to the unilateral case, it

[20] Aldy and Pizer (2009) refer to this as the "competitiveness impact." Using statistical methods, they examine the case of a unilateral U.S. carbon pricing policy only.

does not alter the relative trade impacts—i.e., the proportion of the production losses made up via changes in net imports.

With the H.R. 2454 industry rebates in place, a generally similar pattern emerges, although there are some differences across industries. Of the 1.28 percent reduction in chemicals output in the medium-run unilateral case (Table 14), the fall in exports contributes 0.61 percentage points and the rise in imports contributes 0.26 points, for a combined trade impact of 67 percent. That is, while the changes in the components are different from the no-rebate case (Table 13), the trade impact is similar in both cases. For non-metallic mineral products, the fall in trade due to the rebates is smaller than for chemicals, and the trade impact is only 38 percent , compared to 53 percent without the rebates.

Emissions Leakage at the Industry Level

Moving beyond the trade impacts to estimate emissions leakage at the industry level, we now incorporate changes in international emissions intensity into the calculations. Specifically, we decompose the change in U.S. emissions from each sector into four elements: the change in consumption, the change in exports, the change in imports, and the change in the emissions intensity (see Figure 1 and equation A65 in Appendix A). The change in U.S. emissions due to changes in the quantities of consumption, exports, and imports correspond to those discussed in the previous section on trade impacts. The change in U.S. emissions (or Annex I emissions, in the multilateral case) due to changes in the emissions intensity of output reflects changes in input substitution as U.S. producers (or Annex I producers in the multilateral case) move toward less energy-intensive intermediate goods and less carbon-intensive sources of energy.

Of the 14.95 million ton reduction in U.S. CO_2 emissions from the chemicals, rubber, and plastics sector shown in the first column of Table 15, Figure 1 shows that the reduction in use accounts for 1.13 million tons, reduction of exports accounts for 1.31 tons, increased imports account for 0.26 tons, and input substitution accounts for 12.26 tons. The brown and yellow bars representing the change in trade flows are small relative to the total reduction in emissions for each industry. Of the manufacturing sectors, the largest trade effects are in chemicals, nonmetal mineral products, and ferrous metals sectors. Most of the projected reduction in emissions is due to the changes in the emissions intensity of production (when producers switch to less carbon-intensive sources of energy and intermediate inputs). Exceptions are petroleum refining and oil mining, which see relatively large declines in the demand for their output. For these sectors, the consumption effect is larger than the input substitution effect.

Higher emissions in countries that do not implement carbon pricing policies offset the reduction in U.S. (and Annex I) emissions. The change in emissions in the non-policy regions is the sum of the changes in the levels of consumption, exports, and imports, as well as changes in the carbon intensity in the region. The interagency report (EPA 2009b), however, only considers the total increase in non-Annex I emissions arising from increased net exports to the United States (assuming non-policy countries have the same carbon intensities as the U.S.). We decompose a broader measure of trade-related leakage into the following: the contribution due to the higher quantity of net exports alone (equivalent to assuming other countries have the same carbon intensity as the U.S.), as addressed by the interagency report, and also the contribution due to the differential carbon intensity.

These trade-related leakage components are given in Table 15. The “Total” column follows the interagency report in representing the change in the emissions of non-policy countries due to changes in their net exports to the United States. We break down this concept into three components: the change in emissions due to changes in the quantity of exports to the United States, the change in emissions due to changes in the quantity of imports from the United States (both measured at U.S. carbon intensities), and the change in emissions due to differences in carbon intensity. For example, U.S. emissions in the chemicals, rubber, and plastics sector fall by 14.95 million tons in the multilateral no-rebate case. Total emissions from non-Annex I countries’ net exports of chemicals, rubber, and plastics to the U.S. are higher by 3.96 million tons, of which 0.57 million tons are due to higher exports to the United States, 0.66 million tons are due to lower imports from the United States, and 2.73 million tons are due to higher emissions intensity than in the United States. Dividing 3.96 by 14.95 yields a trade-related leakage rate of 26.5 percent. Using the methodology adopted in the interagency report, the corresponding leakage estimate would be a lower 8.2 percent (=(0.57+ 0.66)/14.95).

The total trade-related leakage rates from the final column in Table 15 are shown in Figure 2, where they are decomposed into “trade-quantity” (i.e., combined exports and imports) and “emissions-intensity” effects, represented by the blue and shaded brown bars, respectively. Among the large energy-intensive manufacturing sectors, the chemicals, rubber, and plastics sector has the highest leakage rate (26.5 percent), followed by ferrous metals (15.0 percent), and nonferrous primary metals (13.4 percent). For nonferrous metals, the emissions-intensity effect (due to differences in production techniques) is small, while it accounts for more than half the leakage for ferrous metals. We can also see that six manufacturing industries have negligible leakage rates because of their low energy intensities.

The results in Table 15 are for the multilateral case without rebates. Table 16 compares the leakage results from Table 15 with the rebate case. Although we saw earlier that rebates generally were effective in reducing or even reversing sectoral output losses (Tables 11 and

12), they do not reduce all trade-related leakage. In every case, however, the reduction in manufacturing-sector emissions is smaller with rebates. The rebates reduce import competition as well as the size of the adjustment. Recall that the leakage rate at the industry level is the change in emissions due to trade divided by the change in U.S. emissions; in the case with rebates, both the numerator and denominator may be smaller. Thus, as can be seen in Table 16, the trade-related leakage rate with rebates may be larger or smaller compared to the no-rebate case.

Aggregate Leakage

We now turn to emissions leakage by country or region. Here we decompose the change in total country emissions into changes for industry and households. We further decompose industry changes into changes in output levels and carbon intensity (due to input substitution). Table 17 presents the decomposition of the change in emissions for countries adopting carbon pricing policies and for non-policy countries, for the unilateral U.S. and Annex I cases, each with and without rebates. We focus here on the long-run (i.e., mobile capital) case.

The first column of Table 17 displays the base-year level of emissions: the United States contributed 6,070 million tons of CO_2 emissions, or 23 percent of global emissions. In the unilateral no-rebate case, U.S. emissions fall by 11.5 percent, or 697 million tons of CO_2. The bottom panel of Table 17 shows that 68.4 percent is due to changes in the input mix, while lower levels of output contribute 20.0 percent, and changes in household consumption contribute 11.6 percent. Thus, the majority of the total CO_2 reduction in the U.S. is due to a fall in the carbon intensity in the electricity, transportation, and other energy-intensive sectors. Changes in the quantity of electricity, transportation, and manufactured goods produced contributes only about a fifth of the total U.S. emissions reduction.

With a unilateral carbon-pricing policy, emissions increase by 146 million tons in the non-policy countries (i.e., in the seven other countries/regions that constitute the rest of the world in this scenario), offsetting almost 21 percent of the U.S. reduction (i.e., the aggregate leakage rate). An increase in the carbon intensity of non-policy countries contributes 58.2 percent of the 146 million ton emissions increase. Higher industry output, part of which is exported to the United States, contributes 32.4 percent, while higher household emissions in the ROW contribute 9.5 percent. Thus, the biggest cause of leakage is the higher use of energy in the production processes in the ROW when the United States adopts a carbon-pricing regime. Higher output in the non-policy countries is also important, partly to cover their increased net exports of carbon-intensive goods to the United States and partly to satisfy their higher demand for the now less-expensive fossil fuels and energy- intensive goods.

With the H.R. 2454 industry rebates, U.S. emissions fall by 9.5 percent, and the aggregate leakage rate is 21.7 percent—slightly larger than in the no-rebate case. This may appear counterintuitive because the rebates are supposed to reduce changes in trade flows. However, the rebates also reduce the U.S. output changes, which in turn reduce the fall in U.S. emissions. There is a smaller reduction of world energy prices with the rebates, leading to a smaller increase in energy consumption in the no-policy regions. Mathematically, both the numerator and denominator of the leakage rate are reduced. We should note that a substantial portion of the rebates go to cover higher costs in the electricity sector, meaning that conservation of electricity use by the non-traded part of the economy is only slightly encouraged by the rebate policy.

We now turn to the case of multilateral action by all Annex I countries. U.S. emissions fall by 663 million tons (10.9 percent) compared to 697 in the unilateral case. Emissions in the other Annex I countries implementing the same carbon price fall by 843 million tons, resulting in total Annex I reductions of 1,506 million tons. Emissions in the non-policy (i.e., non-Annex I) countries rise by 255 million tons for an aggregate leakage rate of 17 percent, a rate more than 4 percentage points lower than in the unilateral case. The composition of the increase in the non-policy region emissions is quite different from the unilateral case: 82 percent is due to input substitution, while changes in output levels are close to zero and households contribute a relatively small 18 percent.

In the multilateral case with rebates, U.S. emissions fall by 539 million tons and the total Annex I reduction is 1,388 million tons. The rise in non-Annex I emissions generates a leakage rate of 17.8 percent compared to 17.0 percent without rebates. Although the rise in non-Annex I emissions in absolute tons is lower, the fall in Annex I emissions is even smaller and the aggregate leakage rate thus rise slightly.

Comment on Leakage Rates

A number of factors influence industry and aggregate leakage rates. Burniaux and Oliveira Martins (2000) use a simplified CGE model to look for key determinants of the magnitude of leakage rates. Of the mechanisms they examine, they find that the supply elasticity of coal and the model's production structure have the most influence on leakage rates. With their preferred parameter values and model structure, they find generally low aggregate leakage rates.

Model closure, wherein exchange rates adjust to "close" the foreign trade account, also may have some influence on leakage rates. In our static model, the trade balance is assumed unchanged by the carbon policy and an exchange rate closes this account. A dynamic model with a transition period that allows trade balances to adjust would likely produce different changes in trade flows and leakage rates.

Industry leakage is sensitive to the import elasticities. The elasticities in our global CGE model are drawn from the GTAP 7 database. While relatively disaggregated for a global CGE model, many of the manufacturing sectors are averages across heterogeneous products. In turn, the elasticities are averages and may not reflect well the import responses for certain subsectors. If we were able to use the same set of sectors that are available in the more disaggregated I-O model, import responses and leakage likely would be greater for some sectors than is currently captured in our global model. Other sectors likely would have smaller impacts.

VII. Conclusions

Inevitably, any broad-based carbon-pricing policy will have disproportionate impacts on energy-intensive, trade-exposed industries. In response to the introduction of such a carbon pricing regime, we find that changes in the carbon intensity of U.S. production are the biggest contributor to total emissions reductions. At the same time, domestic production, profits, and U.S. exports and imports are adversely affected. The key policy development challenges are to 1) identify the industries with the largest output and/or profit losses and understand the full extent and likely duration of the impacts; 2) estimate the trade impacts and emissions leakage associated with the domestic carbon-pricing scheme; and 3) assess to what extent the various impacts are mitigated by offsetting policies, including output-based rebates of the type contained in H.R. 2454, and the implementation of comparable pricing policies in other nations.

We use four modeling approaches as a proxy for the time horizons over which firms can pass through added costs, change the input mix, adopt new technologies, and reallocate capital. While our modeling analyses are based on a fairly detailed list of industries, further disaggregation would certainly show an even broader range of responses. With this caveat, examination of the results of a $15/ton CO_2 price combined with a set of H.R. 2454-style output-based rebates for EITE industries over what we label the very-short-, short-, medium-, and long-run horizons yields a number of observations:

- Measured by the reduction in domestic output, a readily identifiable set of industries is at greatest risk of contraction over both the short and long terms. Within the manufacturing sector, at a relatively aggregate, three- or four-digit NAICS industry classification level, the hardest-hit industries without rebates are petroleum refining, chemicals and plastics, ferrous metals, nonferrous metals, and nonmetallic mineral products.

- The use of the H.R. 2454 rebates can significantly offset the output losses over all four time frames considered. In the short-run, within manufacturing the biggest relative dampening of output losses occurs in ferrous metals, nonferrous metals, and nonmetallic mineral products. In the non-manufacturing sector, the output losses of the electric and gas utilities sectors shrink even more dramatically.
- Industries’ ability to raise prices in the face of the domestic carbon-pricing policy is key to their sustained profitability. With or without rebates, the loss of profits is much smaller in the short-run compared to the very short-run, where it is assumed that higher costs cannot be passed on.
- Focusing on the nearer-term time frames, where certain simplifying assumptions allow for a more disaggregated analysis, we observe that the greatest harm is concentrated in particular sub-segments of the three-digit industries. Without the rebates, the biggest short-run output losses in the manufacturing sector occur in other basic organic chemicals, aluminum, petrochemicals, artificial fibers, and plastic and material resins. With the rebates, the biggest output declines are in other basic organic chemicals, plastic and material resins, textiles, and lime and gypsum. With the rebates, the biggest fall in short-run profits are in these same industries, when some higher costs are passed on to customers.
- Many of the non-manufacturing industries benefit from the switch of expenditures away from carbon-intensive commodities, and so the impact of the policy on their output is more varied. With the rebates, the output of coal mining recovers substantially over the medium term as output in manufacturing and electric utilities recover. However, over the long-run, when capital is allowed to adjust, there is greater substitution away from coal and output falls further. In services, output initially expands with the expenditure switch, but over time as the other industries reduce their cost shock this effect is diminished.
- While the changes in output resulting from the domestic carbon-pricing regime reflect changes in U.S. industrial activity, they do not fully reflect changes in consumption. To understand the latter, one needs to consider the changes in exports and imports. Although the results vary considerably by industry, overall, we find that with or without H.R. 2454 industry rebates, the fall in exports and rise in imports of manufactures offset about half of the fall in U.S. output. Thus, the reduction in consumption is much smaller than the reduction in output.

- The emissions leakage, or change in emissions outside the U.S., is defined to include increased net exports to the U.S. as well as the effect of importing from countries with higher carbon intensities. Overall, this trade-related leakage effect is relatively modest for most industries, on the order of several percentage points for the energy-intensive industries, in line with the results presented in the interagency report (EPA 2009b).
- We also consider a broader definition of industry leakage which includes the effect of increased fossil fuel consumption in those countries not undertaking a carbon-pricing policy. In this more comprehensive measure, the leakage rates are considerably higher. In the absence of the H.R. 2454 industry rebates, we estimate that the long-run leakage rate associated with unilateral U.S. action, including the input substitutions occurring in the non-policy nations, is 21 percent when viewed across the entire economy. With the rebates in place, the leakage rate itself rises to 21.7 percent. This small increase reflects the fact that along with the trade impacts and the input substitutions occurring in the non-policy countries, the rebates themselves encourage U.S. production, thereby increasing U.S. emissions compared to the non-rebate case. With the assumption of parallel action by other Annex I nations, the overall leakage rate falls to 17 percent without rebates and 17.5 percent with them.

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Appendix A: Methodology to Estimate the Effect of a Carbon-Pricing Policy with Offsetting Provisions

This appendix describes our methodology to estimate the effects of carbon policies over various time horizons. In section A.1, we lay out the calculation of the changes to prices, output, and profits. In A.2, we describe the treatment of the H.R. 2454 quota allocations. In A.3, we discuss leakage formulas.

A.1 Methodology for Analyzing Short-Run Effects

This section describes our methodology to estimate the effects of carbon policies over the very short and short-run. The policies include a simple carbon tax and a tax that has provisions to offset some adverse impacts to specific industries. In both cases, revenues from these taxes are transferred back to households.

We follow fairly standard input–output conventions for the notation in the following equations (e.g., Miller and Blair 2009). To have a full accounting of all carbon sources and users, we construct a complete set of accounts for all *n* industries. We carefully distinguish between values and quantities.

Let p_j^X denote the price of industry *j* output to buyers, and p_j^L and p_j^K denote the price of labor and capital inputs. The value of industry *j*'s output at buyers' prices is equal to the value of inputs plus taxes on production:

(A1) $$p_j^X X_j = \sum_i p_i^Q u_{ij} + p_i^L L_i + p_j^K K_j + tax_j \qquad j = 1,2,\ldots,n$$

where X_j is the quantity of output and u_{ij} is the intermediate input of commodity *i* into sector *j* purchased at prices p_i^Q. L_j and K_j are the labor and capital inputs. A matrix whose *j*th column is the input vector of commodities used by industry *j* is the "use" matrix:

(A2) $$\boldsymbol{U^v} = \left[\boldsymbol{u_{ij}^v}\right]$$

Both the detailed industry accounts and input–output tables distinguish between industries and commodities; they are classified using the same names and reference numbers. The hotel industry for example, produces a "hotel lodging" commodity and a "restaurant" commodity. And on the other side, each commodity may be produced by several industries; for example, the restaurant commodity is produced by the hotel and restaurant industries, and the electricity commodity is produced by electric services, federal electric utilities, and S&L government electric utilities. In the notation above, u_{ij} is the use of commodity *i* by industry *j*.

The "activity" matrix, **B**, gives the amount of input *i* required for one unit of output *j*:

(A3) $$b_{ij} = \frac{u_{ij}^v}{X_j^v}; \quad \boldsymbol{B} = [b_{ij}] = \boldsymbol{U}^v[diag(X^v)]^{-1}$$

The row sum of the use matrix is $Ut = \boldsymbol{B}X$, where t is a vector of ones. The corresponding use of labor and capital per unit output are denoted as:

(A4) $$b_j^L = \frac{L_j}{X_j}; \quad b_j^k = \frac{K_j}{X_j}$$

In Part 1 where we analyze the very short-run, we assume that the input mix cannot be changed, or that the activity matrix $\boldsymbol{B}$ is not affected by carbon control policies.

Total final demand, E_i, is the demand for domestic commodity *i* by the final users—consumption, investment, government, and net exports. This corresponds to the familiar expression for gross domestic product: GDP = C + I + G + X - M. Thus, for commodity *i*:

(A5) $$E_i = c_i + v_i + g_i + e_i - i_i; \quad E = [E_i]$$

We will need to consider, separately, gross final domestic demand that excludes net exports:

(A5b) $$E_i^d = c_i + v_i + g_i; \quad E^d = [E_i^d]$$

Let Q_i denote the supply of domestic commodity *i*. The supply–demand balance is written as:

(A6) $$Q_i = \sum_j u_{ij} + E_i \qquad i = 1,2,\ldots,m; \quad Q = [Q_i]$$

In vector form this becomes:

(A6b) $$Q = \boldsymbol{U}t + E = \boldsymbol{B}X + E$$

where t is a vector of ones. The corresponding equation in value terms is simply $Q^v = \boldsymbol{U}^v t + E^v$. Since each commodity may be produced by a few industries, we use the "Make" or "Supply" matrix:

(A7) $$\boldsymbol{V}^v = \left[V_{ji}^v\right]$$

where V_{ji}^v gives the value of commodity *i* produced by industry *j*. The vector of industry output is the row sum of the supply matrix, $X^v = \boldsymbol{V}^v t$; and the vector of commodity output is the column sum, $Q^v = V^{v\prime}t$. Let the share of commodity *i* produced by industry *j* be denoted by d_{ji}. Then the relation between industry output and commodity supply is given by:

(A8) $$X^v = \boldsymbol{D}Q^v; \quad \boldsymbol{D} = \left[d_{ji}\right] = V^v[diag(Q^v)]^{-1}$$

We also use the industry proportion matrix, C, which gives the share of industry *j*'s output going to commodity *i*:

(A9) $$Q^v = CX^v; \quad C = \left[C_{ji}\right] = V^{v\prime}\left[diag(X^v)\right]^{-1}$$

By putting (A3) and (A8) into (A6), we obtain the following well-known relationship between final demand and domestic output (e.g. Miller and Blair 2009):

(A10) $$Q^v = (\boldsymbol{I} - \boldsymbol{BD})^{-1}E^v$$

where $\boldsymbol{I}$ is the identity matrix. $(\boldsymbol{I} - \boldsymbol{BD})^{-1}$ is known as the Leontief inverse, and it tells us that to produce a vector E of final demand commodities, the economy must produce a vector Q of gross output of commodities. In particular, this formulation expresses the additional outputs that must be produced if we want the economy to produce an extra unit of commodity *i* for final users. For example, if we want to produce one more dollar's worth of motor vehicles, the economy must produce additional steel, glass, electricity, etc., which the motor vehicle industry buys as inputs. However, steel production needs motor vehicles, electricity, coal, etc., and electricity needs steel, coal, etc. The Leontief inverse gives us the grand total of extra electricity, coal, etc. that is required for the economy to produce one more dollar of motor vehicles.

The vector of additional output needed for one unit of *i* is thus given by:

(A11) $$\Delta Q^i = (I - BD)^{-1} i_i$$

where i_i is a vector with a 1 in the *i*th element, and zeros everywhere else. Writing out the components of this vector explicitly gives us:

(A12) $$\Delta Q^i = \begin{bmatrix} \Delta Q^i_{farm} \\ \Delta Q^i_{oil} \\ \Delta Q^i_{gas} \\ \vdots \end{bmatrix}$$

With this formulation, we can estimate the total additional carbon emissions due to one more unit of commodity *i* since the vector ΔQ^i gives us the additional coal, crude oil, and gas used.

Let θ_f be the carbon dioxide (CO_2) content per unit of fuel *f*, where the units are the base-year million dollars of fuel *f*. For example, $\theta_{coal} =$ 312 metric tons of CO_2 per million dollars of output in 2006 (see Table 2). This is derived from the energy content per unit fuel (e.g., BTU's per ton of coal), the carbon content per BTU, and the average price per unit fuel ($ per ton).

If fuels did not have non-combustion uses, then the direct and indirect emissions due to producing one unit of commodity *i* may be derived simply by multiplying the primary energy elements in ΔQ^i by their respective carbon content coefficients. Let ΔC_i denote the total carbon emissions due to producing one unit of *i*:

(A13) $$\begin{aligned} \Delta C_i &= \theta_{coal} \Delta Q^i_{coal} + \theta_{oil} \Delta Q^i_{oil} + \theta_{gas} \Delta Q^i_{gas} \\ &= \theta' \Delta Q^i \end{aligned}$$

where $\theta' = (0, \ldots, \theta_{oil}, \theta_{gas}, \theta_{coal}, \ldots, 0)$ is the vector of carbon coefficients with non-zero entries only for the primary fuels. Although the ΔQ^i vector also gives us the additional electricity and additional refined petroleum products used, we do not include them in the calculation because these are secondary products. Clearly, it is the production, not the use of, electricity that generates CO_2, as captured by the coal, oil, and gas elements. Similarly, gasoline, kerosene, etc. are captured at the crude oil stage.

However, crude oil and gas are used as feedstock in the production of chemicals and other products that are not combusted, so that their carbon is not released. Refined petroleum products include lubricants and waxes that are also not combusted. If the carbon-pricing policy exempts such non-fuel use, then the formulas should reflect that. To take these into account, we introduce a combustion ratio ϕ that represents only the combusted portion. We have to distinguish carefully between two types of processes. In our modeling approach, $\phi(i,j)$ is the proportion of fuel *i* that is combusted by industry *j*, a number less than or equal to one. As an example, the gas that is turned into fertilizer and not combusted is represented by the feedstock ratio, $1-\phi(gas\ mining, fertilizer)$. The crude oil that is converted to refined products is not combusted in the refining industry but is eventually combusted by downstream users. In this case, the emissions of the refining industry are represented by multiplying the crude oil input by a small ratio:

$$\phi(oil\ mining, refining) = 0.063$$

The carbon emitted by households, or industry *j*, is calculated by multiplying the gasoline purchased from refining by the emissions coefficient of oil products, and by the combustion ratio recognizing that lubricants and such are not combusted. Similarly, for the other fuels and summing together:

(A14) $$C_j = \theta_{refined}\phi(refined,j)u(refined,j) + \theta_{gas}\phi(gasutil,j)u(gasutil,j) + \dots$$

Unlike eq. (A13), where we considered only the primary fuels, we need to include a separate account for refined petroleum and gas utilities when we recognize non-fuel uses.

To have this separate accounting, we begin by expressing total national emissions as the sum of the industries and domestic final demand use of fuel *f*, and then we sum all fuels:

(A14b) $$C = \sum_f \theta_f \left(\sum_i [\phi_{fi} u_{fi} + E_f^d] \right)$$

$f = coal, oil\ mining, gas\ mining, lpg\ refining, other\ refining, gas\ utilities$

The combustion use of fuel *f* in industry *j* is the quantity used u_{fi} multiplied by a combustion ratio, ϕ_{fj}. National emissions also include those from households and government represented in the final demand vector E^d. In matrix notation:

(A15)
$$\begin{aligned} C &= \theta'[(\phi \circ \mathbf{U})i + E^d] \\ &= \theta'[\phi \circ \mathbf{B}[diag(X)]i + E^d] \\ &= \theta'[\phi \circ \mathbf{B}X + E^d] \\ &= \theta'[\phi \circ \mathbf{BD}Q + E^d] \end{aligned}$$

Where $\phi \cdot u$ is the Hadamard product and i is a vector of ones. The vector of the change in direct and indirect CO_2 emissions due to one more unit of final demand is obtained by substituting in eq. (A11):

(A16)
$$\Delta C' = \begin{bmatrix} \Delta C_1 \\ \vdots \\ \end{bmatrix}' = \theta'[\phi \circ \mathbf{BD}(\mathbf{I} - \mathbf{BD})^{-1} + \mathbf{I}]$$

The change in emissions due to one more unit of commodity *i* used by final demand is:

(A17a)
$$\Delta C_i^{FD} = \sum_f \theta_f [\sum_k \phi_{fk} b_{fk} \sum_j (d_{kj} \Delta Q_j^i)] + \theta_i$$

The change in emissions due to the production of one more unit of *i* is only the first term:

(A17)
$$\Delta C_i = \sum_f \theta_f [\sum_k \phi_{fk} b_{fk} \sum_j (d_{kj} \Delta Q_j^i)]$$

The distinction between eq. (17a) and (17) only matters for the energy commodities. Eq. (A17) represents the (minor) emissions in producing a ton of coal, for example, and (A17a) represents the emissions due to the production and combustion of a ton of coal.

We should emphasize the difference between eq. (A13) and (A17), the second of which includes the combustion ratio term. The ratio is very different from 1.0, and eq. (A17) thus generates a very different estimate of the carbon intensity for some products. The construction of the combustion ratios is described in Appendix B.

The proposed carbon-pricing policies consist of a few distinct elements: a carbon price (due to a carbon tax or emission permits), free allocation of some permits based on historical output or current output, special targets for electric utilities, and restrictions on imports using carbon tariffs or special rules. Some legislative proposals include a provision that quotas or compensation be given to the local distribution companies (LDCs) to limit electricity price increases. Our model represents such a policy as a subsidy to the output of the electric utilities industry. In the case of the H.R. 2454, the subsidy rate is determined by a free allocation of emissions permits equal to 30 percent of total covered emissions and the 2006 industry output for electric utilities.

To take the first element into account, we represent the effect of a carbon price as a tax on the primary fossil fuels in proportion to the carbon content. Given the additional carbon embodied in one unit of commodity *i*, assuming the fixed input–output structure and assuming no change in pricing behavior, the carbon tax at rate \$$\tau^C$ /ton will result in the cost of producing *i* rising by:

(A18) $$\Delta p_i^{Q,c} = t^C \Delta C_i$$

To take into account the output-based quota allocations or other kinds of subsidies, we introduce a "carbon price–offset subsidy" for the sellers of commodity *i*: s_i^C . Taxes or subsidies may be expressed either *ad valorem*, per dollar, or per physical unit. Because our level of aggregation does not include simple items, such as tons of steel coils, we use the more convenient subsidy per dollar of sales. Together with a carbon price, this subsidy changes the cost and, as a result, the price of non-energy commodity *i* by:

(A19) $$\Delta \tilde{p}_i^Q = t^C \Delta C_i - s_i^C P_i^{XO}$$

If the subsidy policy ties the subsidy rate only to the electricity consumed, we label it as $s_{i,elec}^C$. When it ties the rate to electricity and the use of fossil fuels, we label it as $s_{i,total}^C$.[21]

The purchaser's price of commodity *i* is the seller price plus taxes, which includes the carbon tax on the output of the coal mining, oil mining, gas mining, and refining industries. The change in price to purchasers of *i* is therefore:

(A19b) $$\Delta p_i^Q = t^C \Delta C_i - s_i^C P_i^{XO} + t^C \theta_i$$

To repeat, θ_i is only non-zero for i=coal, oil, gas, refining-lpg, refining-other, and gas utilities. That is, the producers of refined products face higher costs of burning crude and in the long-run would charge a higher price to cover the higher costs, less any subsidies. In addition,

[21] Note that the policy is based on 25 percent of an industry's indirect emissions—a point discussed in more detail later in Appendix A. No policy proposals include consideration of the higher costs of non-fuel intermediates, and we do not develop that option here.

the policy puts a carbon tax on the carbon content of the refined products, so the price to users of gasoline in the long-run changes according to the three terms on the right side of A19b.

As explained in section A.2 below, the various pieces of proposed legislation have different subsidies. For each scenario the change in price is:

(A19c) $$\Delta p_i^{Qs} = t^C \Delta C_i - s_{i,s}^C P_i^{XO} + t^C \theta_i \quad s_{i,s}^C = \{0, s_{i,ele}^C, s_{i,total}^C\}$$

H.R. 2454 especially subsidizes electricity sales and compensates certain industries that are deemed energy-intensive, trade-exposed sectors (EITEs). The implicit subsidy that results from permit allocations determined by an industry's direct fuel consumption is denoted by $= s_{i,DC}^C$. The implicit subsidy that results from EITE allocations based on industry's indirect emissions is denoted by $s = s_{i,EL}^C$. This price change will affect both producers and final demand (C, I, G, X). The additional cost to final users is the change in price multiplied by the quantity purchased of each commodity. The total cost to all final users of a $\$\tau^C$ carbon tax, before any changes in behavior, is the sum over all *m* commodities:

(A20) $$\Delta COST^{FD} = \sum_{i=1}^{m} \Delta p_i^Q E_i$$

The change in costs of industry *j* is the change in the prices of inputs multiplied by the quantity of inputs that are assumed to be unchanged in the very-short-run case. The total increase in current costs per dollar of output *j* is:

(A21) $$\Delta COST_j^{VS,s} = \sum_i \Delta p_i^{Qs} B_{ij} \phi_{ij} \; ; s = \{0, ele, total\}$$

We model the carbon tax as if it only applies to the combusted portion by multiplying the input matrix B by the combustion ratio ϕ .

We also want to separate out the total effect on costs into the contributions of primary fuels, electricity, and all other intermediate inputs. That is:

(A22) $$\Delta COST_j^{VS} = \Delta COST_j^{DC} + \Delta COST_j^{EL} + \Delta COST_j^{IN}$$

The directly combusted primary fuels component is the sum of coal, oil, and gas commodities:

(A22b) $$\Delta COST_j^{DC,s} = \sum_f \Delta p_f^{Qs} B_{fj} \phi_{fj}$$

where f=oil mining, gas mining, coal, refining-lpg, refining-other, gas utilities. The electricity component is:

(A22c) $$\Delta COST_j^{EL,s} = \Delta p_{elect}^{Qs} B_{elect,j} \phi_{elect,j}$$

Note that in the absence of subsidies, the above components are given simply by the carbon contributions. θ_j^{DC} denotes the CO_2 per dollar of industry output due to the direct combustion of fossil fuels; θ_j^{EL} denotes the CO_2 per dollar of industry output due to electricity consumption. The higher cost is simply the carbon tax multiplied by the carbon content:

(A22d) $$\Delta COST_j^{DC} = t^C \theta_j^{DC}$$
$$\Delta COST_j^{EL} = t^C \theta_j^{EL}$$

Because we are interested in the total effect on an industry, we need to distinguish between quantities and values, sales revenues and profits. The gross sales revenue is $P_j^X X_j$, and net sales revenue ($P_j^{XO} X_j$) is the gross minus "net taxes on production" (sales tax). The sales tax consists of the existing taxes plus the new carbon tax and any new subsidies for carbon price offsets. Given the tax of τ^C per ton of CO_2, the tax rate per dollar of output in the energy sectors is:

(A23) $$\tau_j^C = t^C \theta_j / p_j^{XO}$$

Let t_j^X denote the existing tax on sales and the new subsidy rate for carbon price offset be s_j^C. With the carbon tax, the purchaser pays a total of:

(A24) $$(1+t_j^X) P_j^{XO} X_j + \tau_j^C P_j^{XO} X_j = P_j^X X_j$$

while the seller receives:

(A25) $$\text{revenue} = (1+s_j^C) P_j^{XO} X_j = (1+s_j^C) \frac{P_j^X X_j - \tau_j^C P_j^{XO} X_j}{1+t_j^X}$$
$$= \tilde{P}_j^{XO} X_j$$

where $\tilde{p}_j^{XO}$ denotes the total revenue received per unit of output by the producer—i.e., the "seller's price" plus subsidy. Let π_j denote the gross return to capital—i.e., sales revenue minus intermediate input costs and labor costs of industry *j*:

(A26) $$\pi_j = \tilde{p}_j^{XO} X_j - \sum_i p_i^Q B_{ij} X_j - p_j^L L_j$$

A.1.1 The Very-Short-Run Horizon

In the very-short-run scenario, quantities cannot be changed. Thus, we calculate the effect of the carbon charge on profits for *j* as if customers do not buy less due to higher prices. This effect is best regarded as occurring only in the very short-run before the market settles down to a new equilibrium. In Figure A1, this effect is represented by a movement from the original equilibrium point A, to the temporary point B vertically above A. Over time, the market moves to point F. In the very short-run, however, we only focus on industry *j* and how the higher input prices of all non-*j* commodities affect its profits. We also regard labor prices to be unchanged in this case. In terms of Figure A1, the buyers continue to pay P_j^X at point A, but the producer faces costs represented at B, with no change in quantities. In the absence of new subsidies, the producer suffers a loss equal to the rectangle defined by side AB. If the producer receives a subsidy, the loss is the rectangle defined by side AC. The change in gross profit to the producer, for each scenario *s*, is:

(A27) $$\begin{aligned}\Delta\pi_j^{VS,s} &= \Delta p_j^{XO} X_j - \sum_i \Delta p_i^{Qs} B_{ij}\phi_{ij} X_j - \Delta p_j^L L_j \\ &= s_{j,s}^c P_j^{XO} X_j - \sum_i \Delta p_i^{Qs} B_{ij}\phi_{ij} X_j \\ &= s_{j,s}^c P_j^{XO} X_j - \Delta COST_j^{VS,s} X_j\end{aligned} \qquad s_{i,s}^C = \{0, s_{i,ele}^C, s_{i,total}^C\}$$

Under the assumption that quantities are unchanged and the output price, excluding the subsidy, is fixed, the change in profits is simply the per dollar change in cost given in (21) multiplied by total output quantity plus subsidies. This definition of changes in very-short-run profits is somewhat inconsistent because we consider how the carbon tax results in higher input prices, p_i^Q, while at the same time assuming that output prices, p_j^X, are unchanged for all industries. We define it in this manner to reflect the industry argument that costs will rise because of a carbon fee but industry will not be able to raise prices or change input quantities. This setup also is a simple, transparent representation of the maximum impact on profits from the higher costs and ignores the fact that input commodity *i* is some other industry's output.

The percentage change in very-short-run profits is simply the weighted share of the percentage change in input prices:

$$\text{(A28)} \qquad \frac{d\pi_j^{VS,s}}{\pi_j} = \frac{s_j^c P_j^{XO} X_j}{\pi_j} - \frac{\Delta COST_j^{VS} X_j}{\pi_j} \qquad s_{i,s}^C = \{0, s_{i,ele}^C, s_{i,total}^C\}$$

$$= \frac{s_{j,s}^c P_j^{XO} X_j}{\pi_j} - \frac{\sum_i dp_i^{Qs} B_{ij} \phi_{ij} X_j}{\pi_j} = \frac{s_{j,s}^c}{\alpha_{Kj}} - \sum_i \frac{dp_i^{Qs}}{p_i^X} \frac{\phi_{ij}\alpha_{ij}}{\alpha_{Kj}}$$

where the α 's denote the cost shares:

$$\text{(A29)} \qquad \alpha_{ij} = \frac{u_{ij}}{p_j^{XO} X_j} \quad \text{i=1,2,...m}$$

$$\alpha_{Kj} = \frac{p_j^K K_j}{p_j^{XO} X_j} = \frac{\pi_j}{p_j^{XO} X_j}$$

A.1.2 The Short-Run Horizon

In the short-run case, we consider a situation in which producers raise their output prices to cover the higher costs but still are not able to substitute cheaper inputs for more expensive carbon-intensive ones. The higher price covers the higher costs but dampens demand along the demand curve. In the absence of new subsidies, we arrive at the new equilibrium point D in Figure A2. We now have to make an assumption about the effect of the output subsidy to offset the carbon price. Consider Figure A2, where the subsidy shifts the long run supply curve out to S2, i.e. when input substitutions are possible.

One could assume that competition would let producers raise prices only to the extent that the new price plus subsidy exactly covers the higher costs. This would mean moving to point E in Figure A2. Alternatively, one could assume that in the short-run, producers raise prices by the amount of the higher costs, and the subsidy is an added revenue source to compensate the reduction in demand. This means that the producer is at point D, selling a quantity X_{SR1} in Figure A2. We believe the first case is more appropriate and focus on point E in the following discussion.

The revenue raised is assumed to be transferred back to households who can then spend it on consumption. We also have to take into account the income effect of the higher prices: the higher price, on electricity say, will lead to a reduction in the quantity of household electricity consumed, but less than in proportion. The expenditures on electricity will thus be higher, leading to less spending on other items. There is also a fall in profits that reduces household disposable income. This is explained below in (A61). We assume that the revenue transferred, and the income diverted, affects spending in proportion to current consumption patterns as represented by c_i in equation (A5). That is, we assume there is an increase in final demand for commodity *i* due to the net income change, ΔE_i^{rr}, equal to:

(A30) $$\Delta E_i^{rr} = \omega C_i$$

where ω is the new transfer to household, less income diverted, as a share of total personal consumption expenditures, YC^{hh}. Equation (A62) below defines the allocation to households, and the share is given by $\omega = \frac{Y^{net}}{YC^{hh}}$.

Let the demand elasticity for output *j* be:

(A31) $$\eta_j = \frac{p_j^X}{X_j}\frac{dX_j}{dp_j^X}$$

For each percentage point increase in price, the producer *j* will make and sell $|\eta_j|$ percent less. In this short-run case, we assume that producers raise the output price by the amount of the increase in unit cost due to the carbon tax, net of any carbon price subsidy:

(A32) $$\frac{dp_j^{XO}}{P_j^{XO}} = \Delta COST_j^{VS} - s_j^c$$

The price to purchasers of *j*'s output is given in eq. (A25), and that is changed by this higher seller's price plus the new carbon tax/permit price:

(A33) $$p_j^X = p_j^{XO}(1+t_j^X) + t^C\theta_j$$

The carbon tax (τ^C in eq. 23) is positive only for *j*=coal, oil and gas. The change in price is:

(A34) $$dp_j^X = dp_j^{XO}(1+t_j^X) + t^C\theta_j$$

And in percentage terms the change in purchaser's price, for each scenario *s*, is:

(A35) $$\frac{dp_j^X}{p_j^X} = \frac{dp_j^{XO}}{p_j^{XO}} + \frac{\tau_j^C}{1+t_j^X}$$

$$\frac{dp_j^{X,s}}{p_j^X} = \Delta COST_j^{VS,s} - s_{js}^c + \frac{\tau_j^C}{1+t_j^X} \quad s_{i,s}^C = \{0, s_{i,ele}^C, s_{i,total}^C\}$$

The percent change in sales and output due to an increase in price to cover the higher cost $\Delta COST_j^{VS}$, net of the subsidy, is thus:

(A36)
$$\frac{dX_j^s}{X_j} = \eta_j \frac{dp_j^{X,s}}{p_j^X} = \eta_j[\Delta COST_j^{VS,s} - s_{js}^c + \frac{\tau_j^C}{1+t_j^X}] \quad s_{i,s}^C = \{0, s_{i,ele}^C, s_{i,total}^C\}$$

The increase in demand for industry output due to revenue recycling and other income effects is given by the Leontief inverse multiplied by the increase in demand given by (A30):

(A36b)
$$\Delta X^{rr} = \mathbf{D}(\mathbf{I} - \mathbf{BD})^{-1} \Delta E^{rr}$$

The total percentage change in sales due to the price change and this income effect is then:

(A36c)
$$\frac{dX_j^s}{X_j} = \eta_j \frac{dp_j^{X,s}}{p_j^X} + \frac{\Delta X_j^{rr}}{X_j}$$

As in the very short-run case we assume that labor prices are unchanged. However, all quantities other than capital input may change in this case. In respond to the lower demand, the domestic producers will make less and buy proportionally fewer variable inputs. Let dX_j denote the change in the quantity of output produced. The change in intermediate input *i* and labor use are given by:

(A37)
$$dU_{ij} = B_{ij} dX_j = B_{ij}[\eta_j X_j \frac{dp_j^X}{p_j^X} + \Delta X_j^{rr}]$$

$$dL_j = b_j^L dX_j = b_j^L[\eta_j X_j \frac{dp_j^X}{p_j^X} + \Delta X_j^{rr}]$$

Note, however, that we continue to hold fixed the amount of input per unit output, i.e., $dB_{ij} = 0$. That is, while we allow the customers of *j* to respond to higher prices, here the producers are still unable to adjust the input mix by substituting cheaper inputs for the more expensive carbon-intensive ones.

Profits are given by sales revenues plus subsidies less variable costs, changing eq. (A26) to:

(A38) $$\pi_j = p_j^{XO} X_j + s_j^c p_j^{XO} X_j - \sum_i p_i^Q B_{ij} X_j - p_j^L L_j$$

The change in profits in this short-run case is the change in revenues less the change in costs, both of which are split into price change and quantity change:

(A39)
$$\begin{aligned} d\pi_j^{SR} &= dp_j^{XO} X_j + s_j^c p_j^{XO} X_j + p_j^{XO} dX_j - \sum_i dp_i^Q B_{ij}\phi_{ij} X_j - \sum_i p_i^Q B_{ij} dX_j - dp_j^L L_j - p_j^L dL_j \\ &= d\tilde{p}_j^{XO} X_j + s_j^c p_j^{XO} X_j + p_j^{XO}[\eta_j X_j \frac{dp_j^X}{p_j^X} + \Delta X_j^{rr}] - \sum_i dp_i^Q B_{ij}\phi_{ij} X_j \\ &\quad - \sum_i p_i^Q B_{ij}[\eta_j X_j \frac{dp_j^X}{p_j^X} + \Delta X_j^{rr}] - p_j^L b_j^L[\eta_j X_j \frac{dp_j^X}{p_j^X} + \Delta X_j^{rr}] \end{aligned}$$

Substituting (A35) into (A39), the percentage change in gross profits may be expressed as:

(A40)
$$\begin{aligned} \frac{d\pi_j^{SR}}{\pi_j^{SR}} &= dp_j^{XO} \frac{X_j}{\pi_j} + s_j^c \frac{p_j^{XO} X_j}{\pi_j} + \frac{X_j p_j^{XO}}{\pi_j}(\frac{\eta_j dp_j^{XO}}{p_j^{XO}} + \frac{\eta_j \tau_j^C}{1+t_j^X} + \frac{\Delta X_j^{rr}}{X_j}) - \sum_i dp_i^Q B_{ij}\phi_{ij} \frac{X_j}{\pi_j} \\ &\quad - \sum_i p_i^Q B_{ij} \frac{X_j}{\pi_j}(\frac{\eta_j dp_j^{XO}}{p_j^{XO}} + \frac{\eta_j \tau_j^C}{1+t_j^X} + \frac{\Delta X_j^{rr}}{X_j}) - p_j^L b_j^L \frac{X_j}{\pi_j}(\frac{\eta_j dp_j^{XO}}{p_j^{XO}} + \frac{\eta_j \tau_j^C}{1+t_j^X} + \frac{\Delta X_j^{rr}}{X_j}) \end{aligned}$$

Recall that the value share of profits in sales revenue is denoted by α_{Kj} (eq. A29), and the value share of labor and intermediate inputs are α_{Lj} and α_{ij}. We may rewrite the profit change as:

(A41)
$$\begin{aligned} \frac{d\pi_j^{SR}}{\pi_j^{SR}} &= (\frac{dp_j^{XO}}{p_j^{XO}} + s_j^c)\frac{1}{\alpha_{Kj}} + \frac{1}{\alpha_{Kj}}(\frac{\eta_j dp_j^{XO}}{p_j^{XO}} + \frac{\eta_j \tau_j^C}{1+t_j^X} + \frac{\Delta X_j^{rr}}{X_j}) - \sum_i \frac{dp_i^Q}{p_i^Q}\frac{\phi_{ij}\alpha_{ij}}{\alpha_{Kj}} \\ &\quad - [\sum_i \frac{\alpha_{ij}}{\alpha_{Kj}} + \frac{\alpha_{Lj}}{\alpha_{Kj}}](\frac{\eta_j dp_j^{XO}}{p_j^{XO}} + \frac{\eta_j \tau_j^C}{1+t_j^X} + \frac{\Delta X_j^{rr}}{X_j}) \\ &= \frac{dp_j^{XO}}{p_j^{XO}}\frac{1}{\alpha_{Kj}}[1 + \eta_j(1 - \sum_i \alpha_{ij} - \alpha_{Lj})] + \frac{s_j^c}{\alpha_{Kj}} + \frac{\eta_j \tau_j^C}{\alpha_{Kj}(1+t_j^X)}(1 - \sum_i \alpha_{ij} - \alpha_{Lj}) \\ &\quad - \sum_i \frac{dp_i^Q}{p_i^Q}\frac{\phi_{ij}\alpha_{ij}}{\alpha_{Kj}} + \frac{1}{\alpha_{Kj}}\frac{\Delta X_j^{rr}}{X_j}(1 - \sum_i \alpha_{ij} - \alpha_{Lj}) \end{aligned}$$

Note that $1-\sum_i \alpha_{ij} - \alpha_{Lj} = \alpha_{Kj}$, and so the change for each scenario s is simply:

(A42) $$\frac{d\pi_j^{SR,s}}{\pi_j^{SR}} = \frac{dp_j^{XO}}{p_j^{XO}} \frac{1+\eta_j \alpha_{Kj}}{\alpha_{Kj}} + \frac{s_{j,s}^c}{\alpha_{Kj}} + \eta_j \frac{\tau_j^C}{1+t_j^X} - \sum_i \frac{dp_i^{Qs}}{p_i^Q} \frac{\phi_{ij}\alpha_{ij}}{\alpha_{Kj}} + \frac{\Delta X_j^{rr}}{X_j}$$

s=no subsidy, elect, total

Compared to the change for the very-short-run case given in eq. (A28), the above expression has three additional terms: the effect of higher sales prices, the effect of higher prices on reducing quantities of input and output (recall that is η_j is negative), and the effect of purchasers responding to the carbon tax on the three fossil fuel commodities, where $\tau_j^C > 0$ by reducing quantities. In other words, the customers of fossil fuel industries not only face more costly fuels due to the higher costs of producing fuels, but also the carbon tax on the fuels.

The net effect on profits is ambiguous in the very short-run because the subsidies could be so large as to overcompensate for the higher costs. In the short-run, too, the ambiguity carries over, and an additional unknown is how the higher prices offset lower quantity of sales.

A.2 Quota Allocations and Other Adjustments

Quota Allocations and Subsidy Rates

Under the H.R. 2454 and other bills, specific industries qualify for assistance in the form of emissions allowance rebates or other subsidies. In H.R. 2454, special treatment is given to four main groups relevant to our analysis: electric utilities (specifically via electricity LDCs), natural gas LDCs, petroleum refining, and EITE industries. Electricity LDCs receive an allocation of emission permits equal to 30 percent of the total amount of permits, and natural gas distribution companies receive 9 percent of total permits. Petroleum refining (excluding the .25 percent allocation given to small business refineries) receives a constant 2 percent of total allowances. For EITE industries, emission rebates correspond with historical direct energy and electricity consumption.

To be deemed an EITE industry, a manufacturing industry must either have an energy or greenhouse gas intensity larger than 5 percent and a trade intensity larger than 15 percent, or have an energy or greenhouse gas intensity larger than 20 percent. If a manufacturing industry meets one of these requirements, they will receive emissions permits to offset cost increases, as detailed in Sec. 764 of H.R. 2454. Note that the trade intensity is calculated as exports plus imports divided by the quantity obtained by summing the industry’s value of shipments and imports.

Because the 30 percent allocation to electric utilities will benefit industries as well as residential consumers, some EITE industries possibly would receive dual benefits: one from suppressed electricity price increase and the other from an allocation of emissions permits that depends on historical electricity consumption. To prevent this, the legislation (subparagraph D of Sec. 764) states that EITE permit allocation will be “adjusted” so that EITE industries do not receive permits for costs increases not incurred due to the LDC allocation to reduce electricity price increases. We implement this clause by allocating 25 percent of the indirect carbon factor calculated under the legislation. As the LDC allocation is likely to benefit large industrial users of electricity, the allocation to natural gas distribution companies is likely to benefit EITE industries that obtain natural gas from distribution companies (as opposed to obtaining it straight from the mine).

The calculation of the H.R. 2454 allocations begins with the list of presumptively eligible sectors classified at the six-digit North American Industry Classification System level provided by the U.S. Environmental Protection Agency. This list includes the value of shipments of these eligible sectors, and we use it to calculate a weighted share of eligible output in our 52 sectors. For each sector *j*, we compute the rebate-qualifying share:

(A43) $$\rho_j^{qualify} = \frac{\sum_{k \in eligible(j)} X_k^v}{X_j^v} \quad j=1,\ldots,52$$

For 2006, we estimated that the electric utilities contributed to about 40 percent of U.S. fossil fuel–related CO_2 emissions. The electricity allocation thus results in a subsidy covering about three quarters of the higher costs of generating electricity. If the permit allocation would completely cover the higher costs, we would compute its value by multiplying the carbon price with the carbon content (carbon intensity multiplied by the output):

(A44) $$R_j^{value,DC} = t^C \theta_j^{DC} X_j^V \quad j\text{=electric utilities}$$

In that case, the subsidy for the price of electricity would be:

(A45a) $$s_{j,DC}^C = \frac{R_j^{value,DC}}{X_j^v} \quad j\text{ =electric utilities}$$

H.R. 2454 specifies that 30 percent of the national cap will be allocated to electric utilities, however, so we calculate the as allocation as:

(A45b) $$R_j^{value,DC} = 0.3 * C$$

where j =electric utilities, and C is the national U.S. emissions of CO_2 in 2006.

Given this offset to cushion the impact of electricity prices in H.R. 2454, we compute the amount of allowances rebated to the EITE industries based on their "direct carbon factor" and 25 percent of their indirect carbon factor.[22] In our model, the suppressed electricity price increase is enjoyed by all industries as well as final demand, and electricity allocation effectively compensates the electric utilities industry for about 75 percent of their emissions. This direct combustion allowance is the carbon intensity multiplied by the qualifying share of the industry's output in 2006:

(A46) $$R_j^{DC} = \rho_j^{qualify} \theta_j^{DC} X_j^V$$

The value of the rebates is simply the allowance multiplied by the carbon price:

(A47) $$R_j^{value,DC} = \tau^C R_j^{DC}$$

The rate of subsidy for industry output embodied in this rebate is thus:

(A48) $$s_{j,DC}^C = \frac{R_j^{value,DC}}{X_j^V}$$

Note that this subsidy rate is zero for most of our 52 industries; it is only positive for the few with a positive $\rho_j^{qualify}$.

Current legislation, however, recognizes the emissions embodied in electricity consumption and provides rebates to EITE industries based on their indirect carbon factor, which is determined by annual output, electricity intensity, and electricity efficiency for each industry. To calculate this, we begin with the electricity efficiency for industry *j*, expressed as the kilowatt hours (kWh) of electricity input per dollar (2006$) of gross output.

[22] Note that as a result of natural gas LDC allocations, we use only 25 percent of natural gas consumption to determine the direct carbon factor in our model.

We derive this intensity from our estimates of total electricity. In Appendix B, we explain how we developed energy use by industry using Manufacturing Energy Consumption Survey data. The electricity input is the dollar value in our rescaled input–output use table divided by the national average price of a kWh. We denote this energy intensity by:

(A49) $$e_j^{elec} = \frac{electricity\ input_j}{X_j^V}\frac{\mathbf{kWh}}{\mathbf{\$}}$$

We further define the carbon intensity for electricity use in industry *j* as the metric tons of CO_2 per million kWh in output:

(A50) $$\xi_{\mathrm{j}}^{\mathbf{elec}} = \boldsymbol{\xi}^{\mathbf{elec}}$$

The allowance rebated for indirect emissions is the industry output multiplied by the tons of carbon embodied in the electricity used:

(A51) $$R_j^{EL} = \rho_j^{qualify}\xi_{\mathrm{j}}^{\mathbf{elec}}\mathbf{e}_{\mathrm{j}}^{\mathbf{elec}}\mathbf{X}_{\mathrm{j}}^{\mathbf{V}}$$

As stated earlier, in our analysis the EITE allocation for an industry's indirect carbon factor is 25 percent of the formula in the legislation (this derives from the fact that provisions in the law prevent these dual benefits to EITE industries). As a result the EITE allocation for indirect emissions is given by:

(A52) $$R_j^{*,EL} = 0.25\rho_j^{qualify}\xi_{\mathrm{j}}^{\mathbf{elec}}\mathbf{e}_{\mathrm{j}}^{\mathbf{elec}}\mathbf{X}_{\mathrm{j}}^{\mathbf{V}}$$

The value of the rebates is simply the allowance multiplied by the carbon price:

(A53) $$R_j^{value,EL} = t^C R_j^{*,EL}$$

and the subsidy rate for electricity use is:

(A54) $$s_{j,EL}^C = \frac{t^C R_j^{*,EL}}{X_j^V}$$

The total carbon price subsidy rate under this alternative policy is:

(A55) $$s_{j,total}^C = s_{j,DC}^C + s_{j,EL}^C$$

Revenue Recycling

In the general equilibrium calculations, the revenue from this new carbon tax is recycled back to the households as part of the assumption about government budget neutrality. In the short-run partial equilibrium framework, we also have to take this revenue into account to provide a complete estimate of the GDP and employment effects. First, define the total allowance revenue used for competitiveness allocations (i.e. for the EITE industries, electric utilities, and natural gas distribution companies) as:

(A56) $$R^{EITE} = \sum_j \left(R_j^{value,DC} + R_j^{value,EL} + R_j^{value,NG} + R_j^{value,EU} \right)$$

The total revenue the government receives under the carbon pricing policy, before any allocations, is given by:

(A57) $$R^{Total} = \tau^C C$$

Subtracting the competitiveness allocations from the gross carbon revenue gives the total sum that is recycled to households:

(A58) $$R^{HH} = R^{Total} - R^{EITE}$$

Household Income Effects

In equation (A36) the change in sales of commodity *j* due to the higher price induced by the carbon tax is given by the demand elasticity, η_j . We assume that households reduce their purchases at the same rate, i.e. their demand curve follows the economy wide demand. The change in household expenditures on commodity *j* is the change in price plus the change in quantity. In the case of inelastic goods, this change in positive and leaves the household with less income to spend on other goods. We take this income effect into account in order to generate a complete accounting of the economy wide effects, even in the partial equilibrium framework.

Let the percentage change in personal consumption expenditures on commodity *j* be given by:

(A59) $$\hat{Y}_j^{hh} = \hat{p}_j + \hat{c}_j$$

Where $\widehat{p_j}$ and $\widehat{c_j}$ are the percentage changes in the price and quantity demanded of by households, respectively. The income effect due to the carbon tax, Y^{τ^C}, is the sum over all commodities:

(A60) $$Y^{\tau^c} = \sum_j (\widehat{p_j} + \widehat{c_j}) p_j C_j$$

Since most of the elasticities are less than one (the reduction in quantities will be smaller than the increase in prices), the carbon tax will raise expenditures for most commodities, ignoring income effects. That is, we expect Y^{τ^C} to be positive, and this means that there is less total effective spending.

A final effect on disposable income comes from the change in profits. The lower profits computed in (A42) means a reduction in short run incomes and this must also be accounted for. In (A58) we gave the expression for the revenue recycled to the households; the total net income effect is thus these transfers less the income effect (Y^{τ^C}), plus the total change in profits ($d\pi^{SR,s}_{total}$):

(A61) $$Y^{net} = R^{HH} - Y^{\tau^C} + d\pi^{SR,s}_{total}$$

The change in profits is, however, endogenous since it depends on the level of output which depends on the income effect. To keep matters simple in this short-run, fixed coefficient, framework, we make an approximation of the iterative process that would make this change in profits consistent.

A.3. Leakage

This section summarizes the detailed discussion in Adkins et al. (2010).

Industry Leakage

In each region *r*, the output of industry *t* is equal to exports less imports plus domestic use:

(A62) $$\tilde{Q}_{i,r} = E\tilde{X}_{i,r} - M\tilde{X}_{t,r} + \tilde{U}D_{t,r}$$

The change in output due to policy *p* compared to the no-policy case (denoted by a 0 superscript) is thus the sum of the changes in domestic use, exports and (negative) imports:

(A63a) $$Q^p_{tr} - Q^0_{tr} = (\tilde{U}D^p_{tr} - \tilde{U}D^0_{tr}) + (E\tilde{X}^p_{tr} - E\tilde{X}^0_{tr}) - (M\tilde{X}^p_{tr} - M\tilde{X}^0_{tr})$$

The decomposition of this output change is given in Tables 13 and 14, expressed as a percentage of base-case output. We define the trade impact as the share of output change offset by trade changes:

(A63b) $$TI_{tr} = \frac{(E\tilde{X}_{tr}^{p} - E\tilde{X}_{tr}^{0}) - (M\tilde{X}_{tr}^{p} - M\tilde{X}_{tr}^{0})}{Q_{tr}^{p} - Q_{tr}^{0}}$$

Emissions from industry *t* is the output multiplied by an emissions factor, $\theta_{tr}^{Q,p}$. We first consider U.S. emissions. The change in U.S. emissions from industry *t* due to policy *p* may be divided into an output level effect and an intensity effect:

(A64) $$\begin{aligned}\Delta(p,t,r=US,I) &= \theta_{t,US}^{Q,p}Q_{t,US}^{p} - \theta_{t,US}^{Q,0}Q_{t,US}^{0} \\ &= \theta_{t,US}^{Q,p}(Q_{t,US}^{p} - Q_{t,US}^{0}) + (\theta_{t,US}^{Q,p} - \theta_{t,US}^{Q,0})Q_{t,US}^{0}\end{aligned}$$

Substituting eq. (A63a) into this, we further decompose the change in U.S. emissions as the sum of the changes in the quantity of domestic use, the quantity of exports, the quantity of imports, and the carbon intensity of U.S. production:

(A65) $$\begin{aligned}\Delta(p,t,US,I) = {} & \theta_{t,US}^{Q,p}[(\tilde{U}D_{t,US}^{p} - \tilde{U}D_{t,US}^{0}) + (E\tilde{X}_{t,US}^{p} - E\tilde{X}_{t,US}^{0}) - (M\tilde{X}_{t,US}^{p} - M\tilde{X}_{t,US}^{0})] \\ & + (\theta_{t,US}^{Q,p} - \theta_{t,US}^{Q,0})Q_{t,US}^{0}\end{aligned}$$

We may further distinguish the trade effects by separating trade with Annex I and non-Annex I countries, denoted by the sets {*plcy*} and {*non*} respectively:

(A66) $$\begin{aligned}\Delta(p,t,US,I) = {} & \theta_{t,US}^{Q,0}[(\tilde{U}D_{t,US}^{p} - \tilde{U}D_{t,US}^{0} \\ & +(\sum_{s\in plcy}\tilde{X}_{trs}^{p} - \tilde{X}_{trs}^{0} + \sum_{s\in non}\tilde{X}_{trs}^{p} - \tilde{X}_{trs}^{0}) \\ & -(\sum_{s\in plcy}\tilde{X}_{tsr}^{p} - \tilde{X}_{tsr}^{0} + \sum_{s\in non}\tilde{X}_{tsr}^{p} - \tilde{X}_{tsr}^{0})] \\ & +(\theta_{t,US}^{Q,p} - \theta_{t,US}^{Q,0})Q_{t,US}^{p}\end{aligned}$$

We mark the terms in colors that are used in Figure 1. The last term (blue) represents the input substitution effect, the first term (purple) represents the reduction in consumption, the second term (brown) represents the reduction in exports, and the third term (green) represents the increase in imports.

Industry leakage is the extent to which the emissions reduction in industry *t* in the United States is offset by emissions increases in the industry *t* in other regions. The increase in emissions in region *r* is due to changes in output levels and changes in input intensities. The changes in output levels, as noted in eq. (A63a), are due to changes in the region's consumption and trade with the United States. For a non-Annex I country *r*, the change is parallel to eq. (A66):

(A67)

$$\begin{aligned}\Delta(p,t,r,I) = {} & \theta_{t,r}^{Q,p}[(\tilde{U}D_{tr}^{p} - \tilde{U}D_{tr}^{0}) \\ & +(\sum_{s \in US} \tilde{X}_{trs}^{p} - \tilde{X}_{trs}^{0} + \sum_{s \in nUS} \tilde{X}_{trs}^{p} - \tilde{X}_{trs}^{0}) - (\sum_{s \in US} \tilde{X}_{tsr}^{p} - \tilde{X}_{tsr}^{0} + \sum_{s \in nUS} \tilde{X}_{tsr}^{p} - \tilde{X}_{tsr}^{0})] \\ & +(\theta_{tr}^{Q,p} - \theta_{tr}^{Q,0})Q_{tr}^{0}\end{aligned}$$

The increase in emissions from industry *t* in country *r* is due to the higher domestic consumption, the higher net exports to the United States, the higher net exports to the non-U.S. countries (denoted by {*nUS*}), and the higher input intensities of that country's industries.

When discussing the leakage, EPA 2009b only considers the net exports to the United States, including the effect of the carbon intensity difference. In this paper, we compute only a parallel leakage for comparison; the complete set of factors described in eq. (A67) is given by Adkins et al. (2010). To compute the parallel leakage, we first rewrite (A67) to consider only trade with the United States, ignoring trade between *r* and the other regions:

(A68)

$$\begin{aligned}\Delta(p,t,r:US,I) = {} & \theta_{t,r}^{Q,p}(\tilde{U}D_{tr}^{p} - \tilde{U}D_{tr}^{0}) \\ & +\theta_{t,r}^{Q,p}(\sum_{s \in US} \tilde{X}_{trs}^{p} - \tilde{X}_{trs}^{0} - \sum_{s \in US} \tilde{X}_{tsr}^{p} - \tilde{X}_{tsr}^{0}) \\ & +\theta_{t,r}^{Q,p}(\sum_{s \in nUS} \tilde{X}_{trs}^{p} - \tilde{X}_{trs}^{0} - \sum_{s \in nUS} \tilde{X}_{tsr}^{p} - \tilde{X}_{tsr}^{0}) \\ & +(\theta_{tr}^{Q,p} - \theta_{tr}^{Q,0})Q_{tr}^{0}\end{aligned}$$

Breaking the trade term up into changes in the level of trade and changes in the carbon intensities, the change in emissions is:

(A69)

$$\begin{aligned}\Delta(p,t,r:US,I) = {} & \theta_{t,r}^{Q,p}(\tilde{U}D_{tr}^{p} - \tilde{U}D_{tr}^{0}) \\ & +\theta_{t,US}^{Q,p}(\sum_{s \in US} \tilde{X}_{trs}^{p} - \tilde{X}_{trs}^{0} - \sum_{s \in US} \tilde{X}_{tsr}^{p} - \tilde{X}_{tsr}^{0}) \\ & +(\theta_{t,r}^{Q,p} - \theta_{t,US}^{Q,p})(\sum_{s \in US} \tilde{X}_{trs}^{p} - \tilde{X}_{trs}^{0} - \sum_{s \in US} \tilde{X}_{tsr}^{p} - \tilde{X}_{tsr}^{0})\end{aligned}$$

$$+\theta_{t,r}^{Q,p}(\sum_{s\in nUS}\tilde{X}_{trs}^{p}-\tilde{X}_{trs}^{0}-\sum_{s\in nUS}\tilde{X}_{tsr}^{p}-\tilde{X}_{tsr}^{0})$$
$$+(\theta_{tr}^{Q,p}-\theta_{tr}^{Q,0})Q_{tr}^{0}$$

With this division, the leakage in industry t due to intensity (or production technique) differences, summing for all regions, is:

(A70) $$\Lambda^{\theta X}(p,t)=\sum_{r\in non-US}(\theta_{t,r}^{Q,p}-\theta_{t,US}^{Q,p})(\tilde{X}_{tr,US}^{p}-\tilde{X}_{tr,US}^{0}-(\tilde{X}_{tUS,r}^{p}-\tilde{X}_{tUS,r}^{0}))$$

In Figure 2, the quantity-of-trade effect is marked with blue bars, and this intensity difference is marked in brown shading. The "trade-related leakage rate" is this sum divided by the total reduction in the United States:

(A71) $$\lambda^{NX}=\frac{\theta_{t,US}^{Q,p}(\sum_{r}\tilde{X}_{tr,US}^{p}-\tilde{X}_{tr,US}^{0}-\sum_{r}\tilde{X}_{tUS,r}^{p}-\tilde{X}_{tUS,r}^{0})+\Lambda^{\theta X}(p,t)}{\Delta(p,t,US,I)}$$

This leakage rate is given in Table 16.

Global Leakage

We now look at the total change in emissions by region due to changes in industry and household behavior. From eq. (A64) above, the change in industrial emissions from r (denoted by I) is the sum for all industries of the *output level effect* and the *input substitution effect*:

(A72) $$\begin{aligned}\Lambda(p,r,I)&=\sum_{t}\theta_{tr}^{Q,p}Q_{tr}^{p}-\sum_{t}\theta_{tr}^{Q,0}Q_{tr}^{0}\\&=\sum_{t}\theta_{tr}^{Q,p}(Q_{tr}^{p}-Q_{tr}^{0})+\sum_{t}(\theta_{tr}^{Q,p}-\theta_{tr}^{Q,0})Q_{tr}^{0}\end{aligned}$$

The change in household emissions (denoted by H) is:

(A73) $$\Lambda(p,r,H)=\sum_{i}\theta_{i,hh,r}\cdot C_{ir}^{p}-\sum_{i}\theta_{i,hh,r}\cdot C_{ir}^{0}$$

The change in U.S. emissions is the sum of three terms: output level, input substitution, and household consumption:

(A74) $$\Delta(US,p)=\Lambda^{Q}(p,US,I)+\Lambda^{\theta}(p,US,I)+\Lambda(p,US,H)$$

The total leakage is the sum of the changes over all the non-policy regions:

(A75)
$$\begin{aligned}\Lambda(p) &= \sum_{r\in non}\Lambda(p,r,I)+\sum_{r\in non}\Lambda(p,r,H)\\ &=\Lambda^{Q}(p,I)+\Lambda^{\theta}(p,I)+\sum_{r\in non}\Lambda(p,r,H)\end{aligned}$$

The second equality breaks the total industry contribution to a sum of the output effect and input-substitution effect. The output effect for total industry leakage is the sum for all regions:

(A76)
$$\Lambda^{Q}(p,I)=\sum_{r\in non}\sum_{t}\theta_{tr}^{Q,p}(Q_{tr}^{p}-Q_{tr}^{0})$$

Similarly, the input substitution effect is:

(A76b)
$$\Lambda^{\theta}(p,I)=\sum_{r\in non}\sum_{t}(\theta_{tr}^{Q,p}-\theta_{tr}^{Q,0})Q_{tr}^{0}$$

The three terms on the right side of (A67) and (A68) are given in Table 17.

The global leakage rate is then simply:

(A77)
$$\lambda(p)=\frac{\Lambda(p)}{\Delta(US,p)}$$

When considering Annex-I multilateral policy, the formulas above are simply rewritten with “US” replaced by summing over Annex I regions; “non-policy” then refers to a summation over the non-Annex I regions.

Appendix B: Data Sources and Construction

To obtain accurate estimates of the industry-specific burdens of a carbon-pricing policy, we calculate the carbon intensity of each industry, including carbon dioxide (CO_2) from direct combustion, the use of electricity, and the relevant process emissions. Two types of information are required in this case: input–output (I-O) tables on the inter-industry flows and industry-specific estimates of the physical quantities of the different fuels consumed. Unfortunately, not all the available value and energy data are designed to complement each other. While the industry data are collected in terms of the North American Industry Classification System

(NAICS), only the energy data for manufacturing are collected on the NAICS basis. Energy data for transportation and services are collected on an end-use basis. A few exceptions to this rule exist, including coal use by the electric utilities industry, but for the most part, accurate energy consumption data by NAICS industry only exist for manufacturing industries. Thus, a key challenge is to develop a consistent set of fuel use estimates across all sectors. In this appendix we describe how we estimate the outputs and inputs, including energy inputs, for the 52 industries identified in our study from these primary data. We note the various weaknesses in the data, including inconsistencies between the different sources, which we hope the research community and government agencies may help resolve.

B.1. Constructing a 52-Sector Input–Output Matrix

The main data for our analysis are from the 2006 annual input–output make and use tables for the U.S. from the Bureau of Economic Analysis (BEA) and the Energy Information Administration's (EIA) Manufacturing Energy Consumption Survey (MECS) (EIA 2006b). Our analysis focuses on 52 industries that have significant detail. Many manufacturing industries are six-digit NAICS industries, and non-manufacturing industries are less than six digits. Data availability drove the choice of industries, as did our focus on the impact of carbon-pricing policies on energy-intensive manufacturing industries.

The 2006 I-O table gives data for 65 primarily of three-digit NAICS industries. As a result, we first aggregated the raw 65-industry table to match the broad two- and three-digit NAICS industries. The BEA provides data for the government sector by including federal and state electric utilities. Since our modeling approach has electric utilities including government utilities, we disaggregate the initial government-sector entries in such a way that the resulting disaggregated industry output for government utilities (from the use table) matches the 2006 industry output of federal and state electric utilities as found in detailed industry output tables available from the BEA. For the disaggregation of federal and state electric utilities in the make table, we assume based on the 2002 benchmark table that federal and state electric utilities only produce an electricity commodity and no other outputs. After disaggregating the federal and state electric utilities from the broad government sector in the 2006 table, we aggregated these within the private electric utilities industry in each of the use and make tables.

After the reallocation of government electric utilities, it was necessary to disaggregate many of the manufacturing (and mining) industries to match our level of detail found in the 52 industries. For example, the 2006 data at this point still contained data on inter-industry transactions at the level of chemicals, whereas our 52 industries is at the level of petrochemicals, fertilizers, etc. To disaggregate the 2006 data, we made used of the inter-industry relationships found in the 2002 benchmark I-O tables. Specifically, in breaking apart the chemicals industry in the 2006 table, we assume that the shares of the inter-industry transactions in the 2002 table for the disaggregated chemicals industries are constant. If, for instance, 20 percent of the use of industry *i*'s output to chemicals is used by the petrochemicals industry, then we assume that in 2006, that amount of industry *i*'s output to petrochemicals shares the same relationship to the grand chemicals industry as it did in 2002.[23] Once the use and make matrices were at the level of 50 of our 52 industries, we removed the diagonal of the use matrix and subtracted this amount from the diagonal of the make matrix. We did this calculation because we assume that industry's use of its own output is primarily the purchase of services within the same industry rather than real output.

B.2 Energy Use

We estimate CO_2 emissions for 52 industrial sectors using quantities of fuel combusted. We consider seven types of energy sources: coal, crude oil, natural gas from gas mining, natural gas from gas utilities, liquefied petroleum gas (lpg) from the refining industry, other refined petroleum products, and electricity. The quantities of these energies for the manufacturing sector are from the MECS and EIA's (2006a) *Annual Energy Review* (AER). For non-manufacturing industries, the quantities of the different fuels consumed are inferred based on a nationwide non-manufacturing average consumption price for each fuel that is computed given domestic industry consumption totals and the MECS data for manufacturing industries, along with the dollar value use of fuels by non-manufacturing industries. Each fuel's industry-level consumption, after all fuel consumption updates, is consistent with national totals available from the EIA.

In the following subsections, we discuss the MECS data as well as the development of price and quantity data of our seven energy sources. One common way of estimating the quantity of energy use at this level of aggregation is to assume that every purchaser pays the same economy average price and then apply that to the values in the I-O table. As we noted earlier in Morgenstern et. al. (2004), this is a poor assumption for some industries. For example, aluminum smelting pays a much lower average price for electricity than other industries. We thus turn to independent measures of energy use quantities to compare with the estimates derived from I-O dollar values.

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[23] Note that we disaggregated oil and gas mining, as well as the petroleum and coal products industry, using earlier data the BEA produced that had this disaggregation.

B.2.1 Manufacturing Energy Consumption Survey

The MECS is the federal government's most comprehensive source of information on energy use by U.S. manufacturing industries. The survey collects data on energy consumption and expenditures, fuel-switching capability, on-site generation of electricity, by-product energy use, and other energy-related topics. The manufacturing sector is defined according to the NAICS. The manufacturing sector (NAICS Sector 31–33) consists of all manufacturing establishments in the 50 states and the District of Columbia. Our analysis is based on 2006 data.

The MECS reports the quantities of coal, coke and breeze, residual fuel oil, distillate fuel oil, natural gas, LPG and natural gas liquids, and net electricity for the manufacturing industries at the six-digit NAICS level. Of specific interest are Table 1.1. Consumption of Energy for All Purposes (First Use); Table 2.1 Energy Used as a Nonfuel (Feedstock); and Table 3.1 Energy Consumption as a Fuel. Some energy quantity data are either too small (*) or withheld (W, Q). We treat the small numbers as zeros. For data that were withheld, we do the best we can to reasonably estimate the consumption value based on total energy use and fuel-use constraints across industries and within a given industry respectively. The details are given for specific fuel uses below. We also adopt other methods to estimate missing values, including energy balance.

The industries found in the MECS tables vary some year-to-year, but they primarily are six-digit NAICS industries (with some broader industries when that level of detail is not available). In addition to providing fuel use by industry, the data were our source of feedstock ratios for manufacturing industries. However, before we could use the data, we had to resolve several issues. First, because they are not required to disclose information that could be used to infer the energy use of a particular firm or small group of firms, the EIA has suppressed the use of a particular fuel at the six-digit industry level in some instances in the raw data. Second, some uses of energy found in the MECS tables actually double-count certain fuel consumption, when that fuel is produced on site.

We took several steps to infer the suppressed values in the original tables. The first step was to impute any suppressed values in MECS's all-purpose energy consumption tables, Table 1.1 and 1.2. Note that in this process, we used the tables corresponding to fuel use measured in BTUs (as opposed to physical units). These are the MECS tables ending in .2. To prevent the data user from simply obtaining suppressed information by means of subtracting the sums in the table from the energy use totals, many of rows with a suppressed value have more than one suppressed value. As a result, we formed an initial guess based on the ratio of total energy consumption for each industry to the total energy consumption across all industries. For an instance where industry *i*'s use of fuel *f* was suppressed, we multiplied the ratio for this industry by the total use of fuel *f* across all industries. Once an initial guess was made, we scaled each initial guess up (or down, depending on the case) until the total energy use for industry *i* (obtained by summing over each of the fuels) was equal to the reported total energy consumption *across all fuels* for this same industry.

In MECS Table 2.2 (feedstock use of energy by industry), many of the suppressed values were the total feedstock energy consumption. When possible, we used the ratio of 2002 total feedstock energy use to total all-purpose energy use, by industry, to estimate this suppressed total. In instances where it was not possible to use this ratio (due to an * for the 2002 feedstock energy consumption), we simply took the total all-purpose energy consumption total (Table 1.2) and subtracted the total non-feedstock use of fuel from MECS Table 3.2. After we estimated the total, we were able to estimate the suppressed feedstock consumption, for a given industry, by taking the estimated total and subtracting the known energy consumption values for other fuels, for a given industry. Note that this last step was possible because the suppression (aside from * suppression) in Table 2.2 was for, at most, one fuel for a given industry. In Table 3.2, we employed the same approach for estimating suppressed values as in Table 1.2.

The second issue with the MECS data is the double-counting of some energy uses from production on-site. To convey the general approach taken to correct for this issue, we will consider the case of iron and steel mills. Table B2 has the initial MECS values for energy consumption for the iron and steel mills industry as well as the steps taken to arrive at the energy consumption numbers included in our study. The * denotes values that are less than 0.5 million. In our study, we assume these are 0 and replace them as such. The last column contains the amount of shipments on energy produced on-site. For the iron and steel industry, one easily can see that the total amount of all-purpose coke and breeze consumption (from Table 1.2) does not equal the total as found by adding up the feedstock use (from Table 2.2) and the non-feedstock use (from Table 3.2). The later is larger, and as a result, we assume that the overcounting is due to processing of coal in coke. We first exclude consumption of coal for feedstock use. We also aggregated the use of "other" fuel into the industry's use of coal. As a result, after removing the initial coal feedstock, we replaced it with the feedstock use of other fuels and updated the total all-purpose coal use to reflect these changes. The next step was to aggregate the other non-feedstock energy consumption into the coal consumption column. We did this residually, such that the total all-purpose coal consumption (after the coal and other fuel aggregation) equals the sum of feedstock and non-feedstock coal use (again after the aggregation of coal and other fuel use). In the last step, we removed the overcounting in the use of coke by replacing the non-feedstock use of coke and breeze with the residual of total all-purpose use and feedstock use. These steps and the resulting values derived from the original table are found in Table B2.

B.2.2 Feedstock Ratios

Feedstock ratios were obtained using the MECS data found in Tables 1.2 and 2.2. The MECS data allowed us to obtain the feedstock ratios for the use of coal, refined products, and natural gas. We calculated the feedstock ratio for the refining industry to be 93.7 percent, based on a report released by the EIA (Schipper 2006) and EIA (2009c) data on barrels of oils that were used at inputs to refineries in 2006. We computed the feedstock ratio by converting the 2002 emissions from petroleum refining into an equivalent number of barrels and then dividing by barrels of oil input for all uses to the petroleum industry in 2006. The initial calculation of national emissions from these fuel consumption numbers and feedstock ratios was slightly larger than the number provided by the EIA for 2006—probably because we only developed feedstock ratios for manufacturing industries. In addition, the industry we refer to as refining-other in our paper produces waxes, oil, and asphalt in addition to refined fuel products; importantly, these latter products are not combusted. As a result, we apply a common feedstock ratio across the board for non-manufacturing industries' use of the refining-other industry's output. The level of this feedstock ratio is 20.6 percent and is set such that the national emissions calculation from the fuel consumption data exactly matches the EPA-provided national emissions.

B.2.3 Process Emissions

Process emissions play a significant role in estimating the effects of a carbon-pricing policy for a select few industries. We updated the emissions derived from the underlying I-O accounts used in the very-short-run and short-run analyses, along with the modeling approaches, to include process emissions for the cement, lime and gypsum, and natural gas distribution industries. Data on process emissions come from EIA (2009b). We obtained process emissions from Table 15 of the report's section on CO_2 emissions. For 2008, total U.S. process emissions were 104 million metric tons, with cement contributing 42 percent, natural gas contributing 30 percent, and limestone consumption contributing 19 percent. The computation of our industries' emissions intensities included process emissions. For a comparison of the relative importance of process emissions for the three industries mentioned, see Table 3, which contains direct, indirect, and process emissions for each of our 52 industries.

B.3 CO_2 Emissions and Intensity

With energy use and feedstock use of each energy source by industry, we are able to calculate the total emissions from direct combustion and indirect energy consumption in 2006.

This information allows us to compute CO_2 emissions per million dollars of fuel consumption for each individual fuel. Table 3 shows total CO_2 emissions intensity by industry. Energy consumption, CO_2 emissions, and CO_2 intensity data are shown in Tables A1–A8.

Figures

Figure 1. Decomposition of Emissions Changes, $15 ton/CO2 (Multilateral, Long Run)

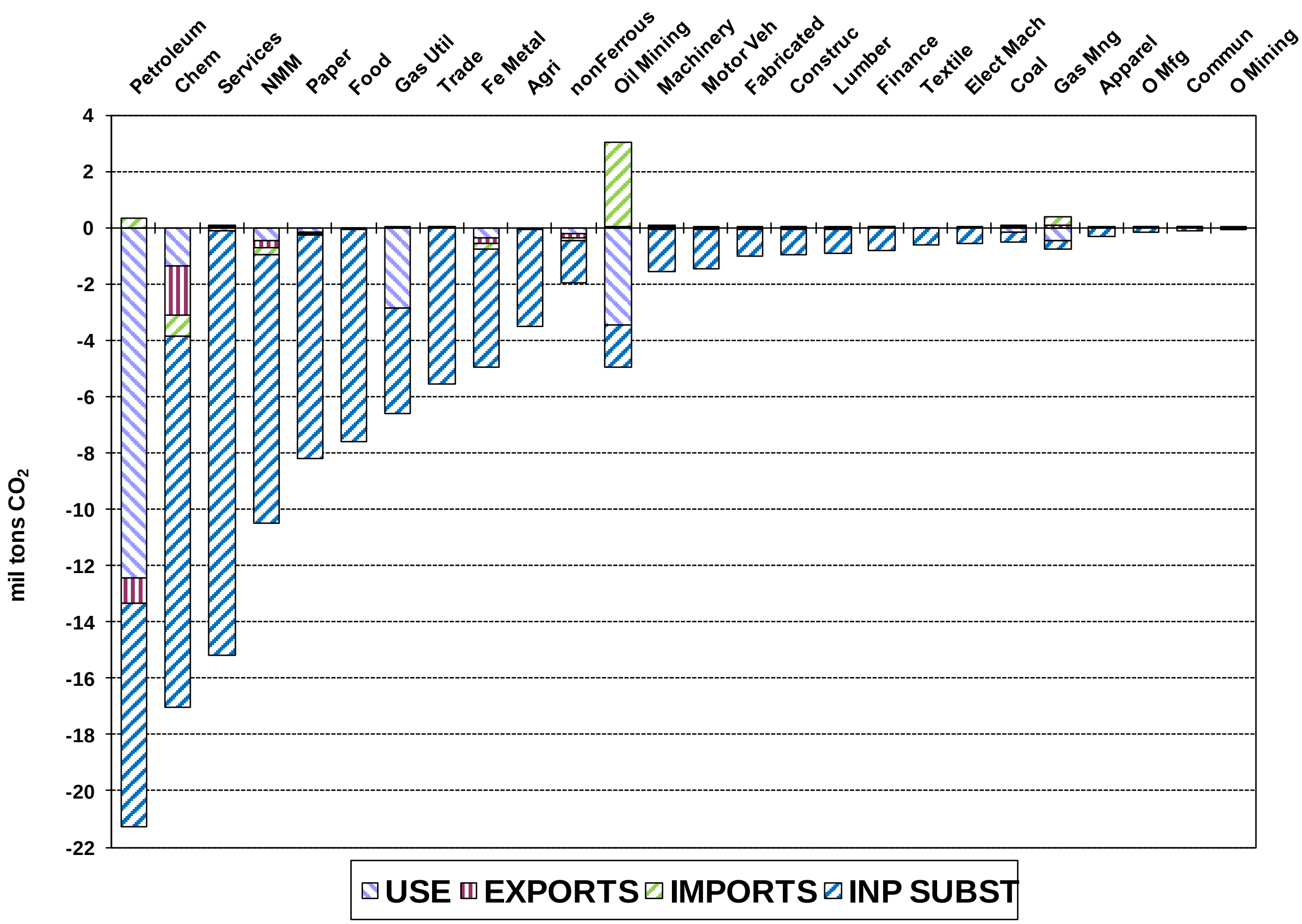


Figure 2. Industry Leakage Due to Trade with the U.S. (Multilateral Policy without Rebates, Long Run)

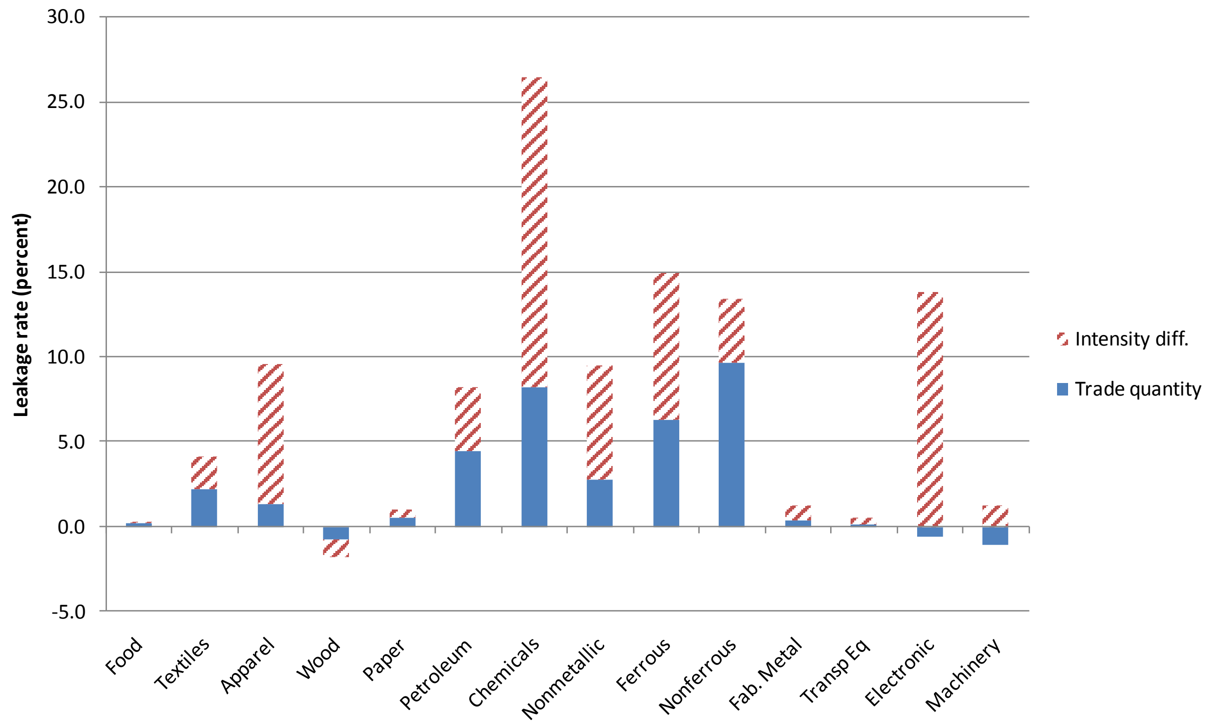


Figure A1. Higher Costs in the Very Short-Run

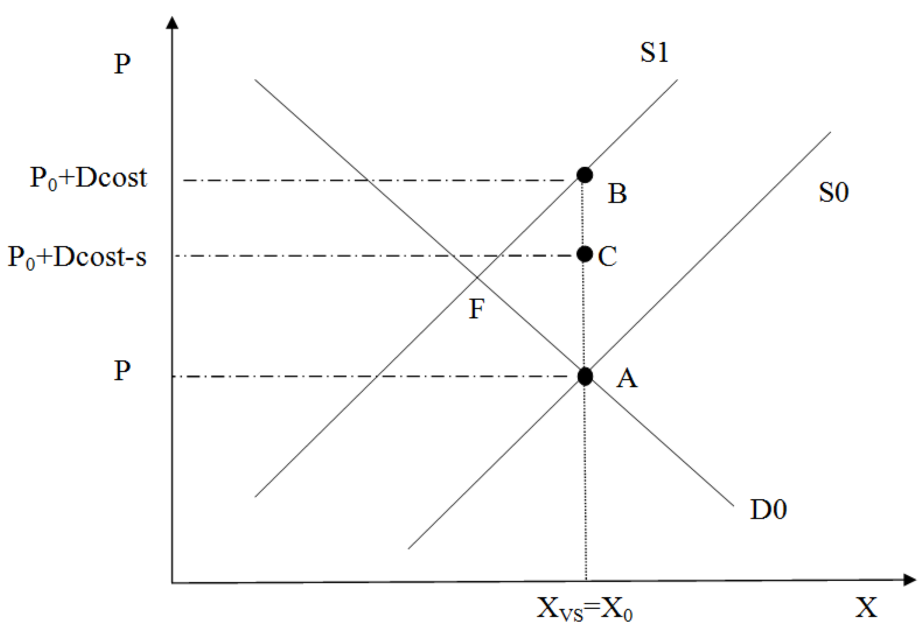
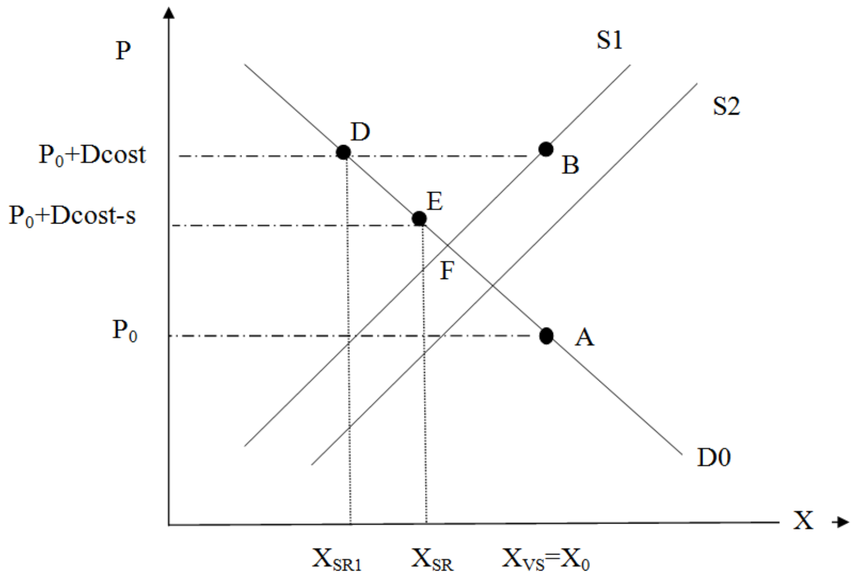


Figure A2. Higher Costs and Output Subsidies in the Short-Run



Tables

Table 1. Energy Costs, Intermediate Inputs and Imports, 2006 (% share)

		% Share of total costs				
		Electricity	Fuel combustion	Total energy (incl non-combustion)	Intermediate inputs	Import share of total use
Manufacturing Industries	Food	1.36	1.70	3.06	75.10	11.04
	Textile	4.13	2.51	6.64	70.96	39.32
	Apparel	0.75	0.33	1.08	43.32	86.97
	Wood & Furniture	2.10	2.57	4.72	58.06	28.26
	Pulp Mills	3.97	7.81	11.78	68.80	51.48
	Paper Mills	5.87	5.31	11.18	61.18	23.20
	Paperboard Mills	8.85	8.81	17.66	66.61	0.60
	Other Papers	1.54	1.09	2.63	61.58	6.22
	Refining-LPG	0.78	9.28	69.02	84.97	0.00
	Refining-Other	0.78	9.29	69.06	84.95	13.95
	Petrochemical Manufacturing	0.83	16.99	21.31	72.45	10.27
	Basic Inorganic Chemical Mfg	8.75	2.97	12.37	66.91	24.14
	Other Basic Organic Chemical Mfg	2.68	12.19	19.45	83.27	25.49
	Plastics and Material Resins	2.33	7.19	25.99	83.74	19.24
	Artificial & Synthetic Fibers, Filaments	5.81	4.98	12.14	81.17	13.14
	Fertilizers	3.22	23.64	26.96	82.07	32.09
	Other Chemical & Plastics	2.44	1.93	5.55	53.89	31.45
	Glass Containers	8.06	12.32	20.39	55.20	18.16
	Cement	10.97	14.12	25.09	52.05	13.92
	Lime and Gypsum	3.35	14.33	17.68	59.57	1.60
	Mineral Wool	5.96	5.99	11.95	56.90	7.88
	Other Nonmetallic Mineral	2.07	4.03	6.27	56.70	19.90
	Iron and Steel Mills and Ferroalloy	5.76	5.30	11.50	63.92	24.53
	Alumina Refining, Primary & Secondary Aluminum	18.17	5.58	25.11	66.33	52.91
	Ferrous Metal Foundries	5.77	3.39	9.33	51.04	6.10
	Non-Ferrous Metal Foundries	3.41	3.64	7.05	66.04	0.00
	Other Primary Metals	3.78	1.96	6.94	66.50	56.69
	Fabricated Metals	1.39	0.96	2.36	54.99	16.87
	Machinery	1.04	0.33	1.37	58.01	43.69
	Computer & Electrical Equipment	0.90	0.23	1.20	50.65	64.37
	Motor Vehicles	1.08	0.59	1.68	71.03	53.70
	Other Transportation Equipment	0.87	0.46	1.33	50.39	32.13
	Miscellaneous Manufacturing	0.62	0.17	0.79	50.39	45.09
Non-Manufacturing Industries	Farms	1.49	4.05	6.52	55.42	10.13
	Forestry, Fishing, etc	0.20	1.22	1.74	23.76	25.56
	Oil Mining	0.31	0.69	1.14	25.68	75.18
	Gas Mining	0.31	0.69	1.14	25.68	20.33
	Coal Mining	0.47	4.62	6.12	46.82	3.14
	Other Mining Activities	0.50	5.62	7.38	44.60	0.47
	Electric Utilities (inc govt enterprises)	0.00	17.27	17.65	32.86	1.09
	Gas Utilities	0.08	0.10	48.89	71.12	0.00
	Construction	0.18	1.74	2.36	47.33	0.00
	Trade	0.78	0.70	1.65	37.32	-1.15
	Air Transportation	0.09	16.87	21.34	57.23	20.57
	Truck Transportation	0.68	7.99	10.72	47.17	1.30
	Other Transportation	0.09	5.16	6.31	35.72	-3.75
	Information	0.34	0.29	0.68	45.74	1.20
	Finance and Insurance	0.27	0.09	0.38	21.70	3.21
	Real Estate and Rental	2.00	0.33	2.40	31.29	0.01
	Business Services	0.58	0.71	1.44	25.74	0.71
	Other Services	0.86	0.48	1.42	39.59	0.10
	Govt exc. Electricity	0.77	3.39	4.82	37.80	0.00

Table 2. Output, Energy Consumption (combustion only) and CO_2 Intensity, 2006

		Output ($bil)	Coal (million sh tons)	Crude oil (million bbls)	Petroleum-LPG (million bbls)	Petroleum-other (million bbls)	Gas (billion cu ft)	Electricity (billion kWh)	Total CO_2 intensity (ton CO_2/mil$)
Manufacturing Industries	Food	580.9	8.2	0.0	0.0	27.7	659.6	82	199
	Textile	57.1	1.7	0.0	0.0	2.8	107.9	25	445
	Apparel	29.2	0.0	0.0	0.0	0.1	7.8	2	59
	Wood & Furniture	159.4	0.9	0.0	0.0	44.2	100.8	36	293
	Pulp Mills	4.1	0.3	0.0	0.0	2.5	12.6	2	807
	Paper Mills	51.4	6.6	0.0	0.0	8.3	176.9	32	875
	Paperboard Mills	23.2	3.6	0.0	0.0	5.7	138.0	22	1,277
	Other Papers	179.3	0.3	0.0	0.0	0.4	170.7	30	160
	Refining-LPG	27.1	0.1	26.5	20.4	0.0	46.6	2	762
	Refining-Other	452.0	2.5	442.9	341.4	0.0	778.5	38	763
	Petrochemical Manufacturing	52.6	0.0	0.5	0.0	96.5	106.9	5	903
	Basic Inorganic Chemical Mfg	25.7	1.1	0.9	0.0	5.2	54.4	24	872
	Other Basic Organic Chemical Mfg	74.7	2.6	1.9	0.0	71.0	297.4	21	866
	Plastics and Material Resins	76.5	0.5	0.5	1.7	22.9	323.6	19	543
	Artificial & Synthetic Fibers, Filaments	8.5	0.5	0.1	0.0	3.1	35.2	5	837
	Fertilizers	11.1	0.1	0.0	0.0	0.2	302.9	4	1,742
	Other Chemical & Plastics	483.1	3.8	0.0	1.7	15.1	538.1	127	254
	Glass Containers	4.4	0.0	0.0	0.0	0.1	48.6	4	1,124
	Cement	10.3	11.7	0.0	0.0	14.0	19.4	12	3,600
	Lime and Gypsum	8.9	4.0	0.0	0.0	4.7	78.7	3	1,799
	Mineral Wool	6.4	0.1	0.0	0.0	0.0	34.0	4	774
	Other Nonmetallic Mineral	89.5	0.3	0.0	0.0	9.0	266.3	20	349
	Iron and Steel Mills and Ferroalloy	83.3	22.7	0.0	0.0	3.6	316.8	51	1,220
	Alumina Refining, Primary & Secondary Aluminum	22.9	0.0	0.0	0.0	0.5	121.5	45	1,702
	Ferrous Metal Foundries	20.0	1.1	0.0	0.0	3.8	34.0	12	717
	Non-Ferrous Metal Foundries	12.5	0.0	0.0	0.0	0.0	38.6	5	435
	Other Primary Metals	46.3	0.4	0.0	0.0	1.6	67.1	19	380
	Fabricated Metals	280.0	0.0	0.0	0.0	1.3	233.0	42	144
	Machinery	290.4	0.0	0.0	0.0	0.9	81.6	33	90
	Computer & Electrical Equipment	418.5	0.0	0.0	0.0	0.5	84.3	40	65
	Motor Vehicles	350.6	0.2	0.0	0.0	3.2	172.8	41	121
	Other Transportation Equipment	175.2	0.1	0.0	0.0	1.3	69.2	16	82
	Miscellaneous Manufacturing	144.5	0.0	0.0	0.0	1.2	15.2	10	48
Non-Manufacturing Industries	Farms	220.1	0.3	0.0	0.0	126.4	51.5	37	353
	Forestry, Fishing, etc	39.8	0.0	0.0	0.0	6.8	1.4	1	80
	Oil Mining	89.9	0.6	0.0	0.0	6.8	8.1	3	72
	Gas Mining	122.5	0.9	0.0	0.0	9.3	11.1	4	72
	Coal Mining	26.1	0.0	0.0	0.0	14.2	26.6	1	313
	Other Mining Activities	158.5	3.9	0.0	0.0	110.8	175.9	8	421
	Electric Utilities (inc govt enterprises)	372.3	1,026.6	0.0	0.0	71.4	6,231.2	0	6,346
	Gas Utilities	115.4	0.0	0.0	0.0	1.5	0.0	1	10
	Construction	1,245.1	0.0	0.0	0.0	310.5	33.4	24	112
	Trade	2,432.8	0.1	0.0	0.0	193.5	109.6	176	76
	Air Transportation	144.6	0.0	0.0	0.0	342.9	0.5	1	947
	Truck Transportation	234.8	0.0	0.0	0.0	268.4	23.8	17	507
	Other Transportation	399.7	0.1	0.0	0.0	232.3	858.5	4	355
	Information	1,013.6	0.0	0.0	0.0	24.6	100.3	36	34
	Finance and Insurance	1,366.2	0.0	0.0	0.0	12.8	31.8	39	21
	Real Estate and Rental	2,301.8	0.3	0.0	0.0	73.5	161.2	450	126
	Business Services	2,142.8	0.2	0.0	0.0	192.7	152.5	132	75
	Other Services	3,014.2	0.1	0.0	0.0	127.2	637.3	273	82
	Govt exc. Electricity	2,608.7	1.2	0.0	0.0	809.6	2,867.4	218	235

Table 3. Carbon Emissions Summary and CO_2 Intensities

		Total CO_2 emissions (thousand metric tons) from:			Total CO_2 intensity (metric tons CO_2 per million $ output)
		Fossil fuel consumption	Electricity consumption	Process emissions	
Manufacturing Industries	Food	62,952.4	52,575.4	0.0	198.9
	Textile	10,320.7	15,052.4	0.0	444.7
	Apparel	476.9	1,241.3	0.0	58.9
	Wood & Furniture	24,845.9	21,890.0	0.0	293.1
	Pulp Mills	2,253.3	1,093.8	0.0	807.2
	Paper Mills	25,813.1	19,102.9	0.0	874.6
	Paperboard Mills	16,732.8	12,912.7	0.0	1,277.4
	Other Papers	10,047.4	18,716.1	0.0	160.4
	Refining-LPG	19,201.0	1,429.1	0.0	762.3
	Refining-Other	320,879.1	23,883.2	0.0	762.8
	Petrochemical Manufacturing	44,371.2	3,109.1	0.0	902.5
	Basic Inorganic Chemical Mfg	7,572.2	14,806.6	0.0	871.5
	Other Basic Organic Chemical Mfg	50,340.1	14,345.6	0.0	865.9
	Plastics and Material Resins	28,454.9	13,118.8	0.0	543.5
	Artificial & Synthetic Fibers, Filaments	4,078.5	3,041.5	0.0	836.7
	Fertilizers	16,854.7	2,411.7	0.0	1,742.0
	Other Chemical & Plastics	43,185.8	79,324.5	0.0	253.6
	Glass Containers	2,705.8	2,237.9	0.0	1,124.5
	Cement	29,309.7	7,788.1	46,700.0	3,599.5
	Lime and Gypsum	13,913.6	2,184.7	16,500.0	1,799.2
	Mineral Wool	2,144.1	2,832.2	0.0	774.0
	Other Nonmetallic Mineral	18,800.7	12,471.8	0.0	349.2
	Iron and Steel Mills and Ferroalloy	62,887.6	38,809.8	0.0	1,220.4
	Alumina Refining, Primary & Secondary Aluminum	6,850.8	32,167.1	0.0	1,702.4
	Ferrous Metal Foundries	5,445.6	8,927.9	0.0	717.1
	Non-Ferrous Metal Foundries	2,112.5	3,331.9	0.0	434.5
	Other Primary Metals	5,050.5	12,542.8	0.0	379.7
	Fabricated Metals	13,275.4	27,117.9	0.0	144.3
	Machinery	4,910.1	21,337.4	0.0	90.4
	Computer & Electrical Equipment	4,800.5	22,203.6	0.0	64.5
	Motor Vehicles	11,049.9	31,497.0	0.0	121.4
	Other Transportation Equipment	4,422.3	9,974.2	0.0	82.2
	Miscellaneous Manufacturing	1,306.9	5,602.2	0.0	47.8
Non-Manufacturing Industries	Farms	53,599.2	24,050.0	0.0	352.7
	Forestry, Fishing, etc	2,769.4	422.1	0.0	80.2
	Oil Mining	4,411.9	2,013.2	0.0	71.5
	Gas Mining	6,015.3	2,744.8	0.0	71.5
	Coal Mining	7,086.9	1,092.1	0.0	313.0
	Other Mining Activities	61,185.8	5,589.9	0.0	421.4
	Electric Utilities (inc govt enterprises)	2,362,712.2	0.0	0.0	6,346.4
	Gas Utilities	609.3	567.9	26,600.0	10.2
	Construction	125,084.7	14,343.9	0.0	112.0
	Trade	83,082.1	102,921.3	0.0	76.5
	Air Transportation	136,143.8	784.1	0.0	947.0
	Truck Transportation	107,835.8	11,220.5	0.0	507.0
	Other Transportation	139,444.1	2,275.7	0.0	354.6
	Information	15,241.8	19,653.2	0.0	34.4
	Finance and Insurance	6,835.0	21,952.7	0.0	21.1
	Real Estate and Rental	38,506.1	250,394.6	0.0	125.5
	Business Services	85,300.2	76,420.6	0.0	75.5
	Other Services	85,500.2	162,546.1	0.0	82.3
	Govt exc. Electricity	480,472.4	132,616.8	0.0	235.0

Table 4a. Total Permit Allocations to EITE Industries (2006)

	EITE Allocations for direct carbon factor (53% of emissions from NG) + 25% of indirect carbon factor			
		Amount (mil $)	Subsidy rate (% of Output)	Qualifying share of industry output
Manufacturing Industries	Food	8.9	0.002%	1.4%
	Textile	3.5	0.01%	1.6%
	Apparel	0.0	-	0.0%
	Wood & Furniture	16.9	0.01%	4.1%
	Pulp Mills	33.2	0.80%	100.0%
	Paper Mills	396.7	0.77%	100.0%
	Paperboard Mills	0.0	-	0.0%
	Other Papers	0.0	-	0.0%
	Refining-LPG	114.1	0.42%	100.0%
	Refining-Other	1,905.8	0.42%	100.0%
	Petrochemical Manufacturing	648.2	1.23%	100.0%
	Basic Inorganic Chemical Mfg	167.5	0.65%	100.0%
	Other Basic Organic Chemical Mfg	778.8	1.04%	100.0%
	Plastics and Material Resins	0.0	-	0.0%
	Artificial and Synthetic Fibers and Filaments	71.6	0.84%	100.0%
	Fertilizers	63.7	0.58%	32.4%
	Other Chemical & Plastics	87.8	0.02%	12.4%
	Glass Containers	32.6	0.74%	100.0%
	Cement	460.3	4.47%	100.0%
	Lime and Gypsum	35.8	0.40%	18.5%
	Mineral Wool	29.5	0.46%	100.0%
	Other Nonmetallic Mineral	44.3	0.05%	18.9%
	Iron and Steel Mills and Ferroalloy	942.8	1.13%	100.0%
	Alumina Refining, Primary & Secondary Aluminum	168.0	0.73%	100.0%
	Ferrous Metal Foundries	0.0	-	0.0%
	Non-Ferrous Metal Foundries	0.0	-	0.0%
	Other Primary Metals	18.5	0.04%	20.3%
	Fabricated Metals	0.0	-	0.0%
	Machinery	0.0	-	0.0%
	Computer & Electrical Equipment	0.0	-	0.0%
	Motor Vehicles	0.0	-	0.0%
	Other Transportation Equipment	0.0	-	0.0%
	Miscellaneous Manufacturing	0.0	-	0.0%
	Allocations for electric and gas utilities			
	Electric Utilities (inc govt enterprises)	26,933.0	7.23%	-
	Gas Utilities	8,079.8	7.00%	-
	Total	41,041.5		

Table 4b. Total Permit Allocations in 29 Sector Model (2006)

	Subsidy for medium/long-run model based on Table 3		
	Amount (mil $)	Industry output (mil $)	Subsidy rate (% of output)
Food, Beverages, and Tobacco	8.9	580,921.1	0.00%
- Food			
Textiles	3.5	57,061.5	0.01%
- Textile			
Wearing Apparel and Leather	0.0	29,184.2	-
- Apparel			
Wood	16.9	159,431.8	0.01%
- Wood and furniture			
Paper and Publishing	430.0	258,038.3	0.17%
- Pulp mills			
- Paper mills			
- Paperboard mills			
- Other papers			
Petroleum and Coal Products	2,019.9	479,059.3	0.42%
- Refining-lpg			
- Refining-other			
Chemicals, Rubber, and Plastics	1,817.7	732,146.7	0.25%
- Petrochemical manufacturing			
- Basic Inorganic Chemical Mfg			
- Other Basic Organic Chemical Mfg			
- Plastics and Material Resins			
- Artificial and Synthetic Fibers and Filaments			
- Fertilizers			
- Other Chemical & Plastics			
Non-Metallic Mineral Products	602.5	119,622.8	0.50%
- Glass containers			
- Cement			
- Lime and Gypsum			
- Mineral Wool			
- Other Nonmetallic Mineral			
Ferrous Metals	942.8	103,377.7	0.91%
- Ferrous Metal Foundries			
Nonferrous primary metals	186.5	81,780.0	0.23%
- Non-Ferrous Metal Foundries			
Fabricated Metal Products	0.0	280,007.7	-
- Fabricated Metals			
Machinery	0.0	290,442.3	-
- Machinery			
Electronic equipment	0.0	418,529.3	-
- Computer & Electrical Equipment			
Transportation Equipment	0.0	525,825.5	-
- Motor Vehicles			
- Other Transportation Equipment			
Other Manufacturing	0.0	144,487.6	-
- Miscellaneous Manufacturing			
Electric Utilities	26,933.0	372,291.2	7.23%
Gas manuf. and distribution	8,079.8	115,350.4	7.00%

Table 5. Very-Short-Run Effect of $15/ton CO_2 Tax on Industry Prices (% Change in Industry Output Price)

	$dp^{X,s}/p^{X,s} = \Delta cost^{VS,s} - s^C + \tau^C/(1+t^X)$	Price change (No Subsidy)	Price change (Total Subsidy)
Manufacturing Industries	Food	0.81%	0.61%
	Textile	1.75%	1.09%
	Apparel	0.50%	0.42%
	Wood & Furniture	0.83%	0.59%
	Pulp Mills	1.76%	0.38%
	Paper Mills	1.89%	0.33%
	Paperboard Mills	2.43%	1.30%
	Other Papers	0.94%	0.61%
	Refining-LPG	22.39%	21.75%
	Refining-Other	9.84%	9.21%
	Petrochemical Manufacturing	2.51%	0.89%
	Basic Inorganic Chemical Mfg	1.65%	0.32%
	Other Basic Organic Chemical Mfg	3.52%	1.91%
	Plastics and Material Resins	2.56%	1.86%
	Artificial & Synthetic Fibers, Filaments	2.32%	0.83%
	Fertilizers	2.95%	0.93%
	Other Chemical & Plastics	1.11%	0.74%
	Glass Containers	2.18%	0.06%
	Cement	5.65%	0.22%
	Lime and Gypsum	3.35%	2.04%
	Mineral Wool	1.65%	0.33%
	Other Nonmetallic Mineral	1.81%	1.05%
	Iron and Steel Mills and Ferroalloy	2.21%	0.35%
	Alumina Refining, Primary & Secondary Aluminum	2.39%	0.01%
	Ferrous Metal Foundries	1.39%	0.73%
	Non-Ferrous Metal Foundries	1.32%	0.68%
	Other Primary Metals	1.24%	0.57%
	Fabricated Metals	0.85%	0.48%
	Machinery	0.60%	0.42%
	Computer & Electrical Equipment	0.40%	0.30%
	Motor Vehicles	0.73%	0.54%
	Other Transportation Equipment	0.49%	0.36%
	Miscellaneous Manufacturing	0.51%	0.42%
Non-Manufacturing Industries	Farms	0.94%	0.77%
	Forestry, Fishing, etc	0.33%	0.30%
	Oil Mining	16.39%	16.33%
	Gas Mining	9.10%	9.04%
	Coal Mining	132.41%	132.34%
	Other Mining Activities	0.94%	0.82%
	Electric Utilities (inc govt enterprises)	9.03%	1.79%
	Gas Utilities	8.93%	1.92%
	Construction	0.54%	0.50%
	Trade	0.25%	0.19%
	Air Transportation	1.78%	1.70%
	Truck Transportation	1.02%	0.93%
	Other Transportation	0.63%	0.60%
	Information	0.24%	0.20%
	Finance and Insurance	0.11%	0.09%
	Real Estate and Rental	0.30%	0.16%
	Business Services	0.24%	0.19%
	Other Services	0.31%	0.24%
	Govt exc. Electricity	0.57%	0.46%

Table 6. Very-Short-Run Time Horizon: Percent Increase in Costs due to a $15/ton price of CO_2; no Allocations Scenario

	$\Delta costs^{VS,s}$ with s = no subsidy	Total cost ($\Delta cost^{VS}$)	Fuel cost	Purchased electricity	Indirect cost
Manufacturing Industries	Food	0.81%	0.20%	0.12%	0.49%
	Textile	1.75%	0.32%	0.36%	1.07%
	Apparel	0.50%	0.03%	0.07%	0.40%
	Wood & Furniture	0.83%	0.27%	0.18%	0.38%
	Pulp Mills	1.76%	0.95%	0.35%	0.47%
	Paper Mills	1.89%	0.86%	0.51%	0.51%
	Paperboard Mills	2.43%	1.27%	0.77%	0.39%
	Other Papers	0.94%	0.11%	0.13%	0.69%
	Refining-LPG	1.40%	1.20%	0.07%	0.13%
	Refining-Other	1.35%	1.15%	0.07%	0.13%
	Petrochemical Manufacturing	2.51%	1.66%	0.07%	0.78%
	Basic Inorganic Chemical Mfg	1.65%	0.41%	0.76%	0.48%
	Other Basic Organic Chemical Mfg	3.52%	1.26%	0.23%	2.02%
	Plastics and Material Resins	2.56%	0.72%	0.20%	1.64%
	Artificial & Synthetic Fibers, Filaments	2.32%	0.63%	0.51%	1.18%
	Fertilizers	2.95%	2.26%	0.28%	0.41%
	Other Chemical & Plastics	1.11%	0.21%	0.21%	0.69%
	Glass Containers	2.18%	1.19%	0.71%	0.29%
	Cement	5.65%	4.46%	0.95%	0.24%
	Lime and Gypsum	3.35%	2.61%	0.29%	0.45%
	Mineral Wool	1.65%	0.64%	0.52%	0.49%
	Other Nonmetallic Mineral	1.81%	0.40%	0.18%	1.23%
	Iron and Steel Mills and Ferroalloy	2.21%	1.25%	0.50%	0.46%
	Alumina Refining, Primary & Secondary Aluminum	2.39%	0.53%	1.58%	0.28%
	Ferrous Metal Foundries	1.39%	0.48%	0.50%	0.41%
	Non-Ferrous Metal Foundries	1.32%	0.35%	0.30%	0.67%
	Other Primary Metals	1.24%	0.21%	0.33%	0.70%
	Fabricated Metals	0.85%	0.09%	0.12%	0.64%
	Machinery	0.60%	0.03%	0.09%	0.48%
	Computer & Electrical Equipment	0.40%	0.02%	0.08%	0.30%
	Motor Vehicles	0.73%	0.06%	0.09%	0.58%
	Other Transportation Equipment	0.49%	0.05%	0.08%	0.37%
	Miscellaneous Manufacturing	0.51%	0.02%	0.05%	0.43%
Non-Manufacturing Industries	Farms	0.94%	0.42%	0.14%	0.38%
	Forestry, Fishing, etc	0.33%	0.12%	0.02%	0.20%
	Oil Mining	0.31%	0.08%	0.03%	0.20%
	Gas Mining	0.31%	0.08%	0.03%	0.20%
	Coal Mining	0.69%	0.43%	0.04%	0.23%
	Other Mining Activities	0.94%	0.61%	0.04%	0.29%
	Electric Utilities (inc govt enterprises)	9.03%	8.95%	0.00%	0.08%
	Gas Utilities	0.17%	0.01%	0.01%	0.15%
	Construction	0.54%	0.17%	0.02%	0.35%
	Trade	0.25%	0.06%	0.06%	0.13%
	Air Transportation	1.78%	1.62%	0.01%	0.15%
	Truck Transportation	1.02%	0.79%	0.06%	0.17%
	Other Transportation	0.63%	0.49%	0.01%	0.13%
	Information	0.24%	0.03%	0.03%	0.18%
	Finance and Insurance	0.11%	0.01%	0.02%	0.08%
	Real Estate and Rental	0.30%	0.03%	0.16%	0.12%
	Business Services	0.24%	0.07%	0.05%	0.12%
	Other Services	0.31%	0.05%	0.07%	0.19%
	Govt exc. Electricity	0.57%	0.34%	0.07%	0.17%

Table 7. Very-Short-Run Time Horizon: Percent Increase in Costs due to a $15/ton price of CO_2, with WM Allocations

	$\Delta costs^{VS,s}$ with s = total	Total cost	Fuel cost	Purchased electricity	Indirect cost
Manufacturing Industries	Food	0.61%	0.11%	0.02%	0.48%
	Textile	1.10%	0.18%	0.06%	0.85%
	Apparel	0.42%	0.01%	0.01%	0.40%
	Wood & Furniture	0.60%	0.22%	0.03%	0.35%
	Pulp Mills	1.18%	0.70%	0.06%	0.42%
	Paper Mills	1.11%	0.60%	0.09%	0.42%
	Paperboard Mills	1.30%	0.81%	0.14%	0.35%
	Other Papers	0.61%	0.04%	0.02%	0.55%
	Refining-LPG	1.18%	1.05%	0.01%	0.12%
	Refining-Other	1.14%	1.01%	0.01%	0.11%
	Petrochemical Manufacturing	2.12%	1.50%	0.01%	0.62%
	Basic Inorganic Chemical Mfg	0.98%	0.39%	0.14%	0.44%
	Other Basic Organic Chemical Mfg	2.96%	1.16%	0.04%	1.75%
	Plastics and Material Resins	1.86%	0.50%	0.04%	1.32%
	Artificial & Synthetic Fibers, Filaments	1.67%	0.58%	0.09%	1.00%
	Fertilizers	1.51%	1.06%	0.05%	0.39%
	Other Chemical & Plastics	0.76%	0.12%	0.04%	0.61%
	Glass Containers	0.80%	0.39%	0.13%	0.28%
	Cement	4.69%	4.28%	0.17%	0.24%
	Lime and Gypsum	2.44%	1.94%	0.05%	0.44%
	Mineral Wool	0.79%	0.24%	0.09%	0.45%
	Other Nonmetallic Mineral	1.10%	0.18%	0.03%	0.89%
	Iron and Steel Mills and Ferroalloy	1.48%	0.95%	0.09%	0.44%
	Alumina Refining, Primary & Secondary Aluminum	0.74%	0.20%	0.29%	0.26%
	Ferrous Metal Foundries	0.73%	0.34%	0.09%	0.30%
	Non-Ferrous Metal Foundries	0.68%	0.10%	0.05%	0.53%
	Other Primary Metals	0.61%	0.09%	0.06%	0.46%
	Fabricated Metals	0.48%	0.03%	0.02%	0.42%
	Machinery	0.42%	0.01%	0.02%	0.39%
	Computer & Electrical Equipment	0.30%	0.01%	0.01%	0.28%
	Motor Vehicles	0.54%	0.02%	0.02%	0.50%
	Other Transportation Equipment	0.36%	0.02%	0.01%	0.33%
	Miscellaneous Manufacturing	0.42%	0.01%	0.01%	0.40%
Non-Manufacturing Industries	Farms	0.77%	0.39%	0.02%	0.36%
	Forestry, Fishing, etc	0.30%	0.11%	0.00%	0.18%
	Oil Mining	0.25%	0.07%	0.00%	0.17%
	Gas Mining	0.25%	0.07%	0.00%	0.17%
	Coal Mining	0.62%	0.40%	0.01%	0.22%
	Other Mining Activities	0.82%	0.58%	0.01%	0.24%
	Electric Utilities (inc govt enterprises)	9.02%	8.95%	0.00%	0.08%
	Gas Utilities	0.16%	0.01%	0.00%	0.15%
	Construction	0.50%	0.16%	0.00%	0.33%
	Trade	0.19%	0.05%	0.01%	0.13%
	Air Transportation	1.70%	1.55%	0.00%	0.15%
	Truck Transportation	0.93%	0.75%	0.01%	0.17%
	Other Transportation	0.60%	0.47%	0.00%	0.12%
	Information	0.20%	0.02%	0.01%	0.17%
	Finance and Insurance	0.09%	0.01%	0.00%	0.08%
	Real Estate and Rental	0.16%	0.02%	0.03%	0.11%
	Business Services	0.19%	0.06%	0.01%	0.12%
	Other Services	0.24%	0.04%	0.01%	0.19%
	Govt exc. Electricity	0.46%	0.29%	0.01%	0.16%

Table 8. Short Run Time Horizon with Full Revenue Recycling: % Change in Output due to a 15/ton CO_2 Tax

	dX/X	Unilateral Without H.R. 2454 allocations	Multilateral Without H.R. 2454 allocations	Unilateral With H.R. 2454 allocations	Multilateral With H.R. 2454 allocations
Manufacturing Industries	Food	0.06%	0.13%	-0.21%	-0.17%
	Textile	-2.43%	-1.36%	-1.75%	-1.12%
	Apparel	1.79%	1.37%	-0.15%	-0.50%
	Wood & Furniture	-0.60%	-0.34%	-0.57%	-0.40%
	Pulp Mills	-0.41%	-0.04%	-0.05%	-0.06%
	Paper Mills	-0.61%	-0.18%	-0.06%	-0.06%
	Paperboard Mills	-1.05%	-0.42%	-0.65%	-0.35%
	Other Papers	-0.20%	-0.01%	-0.26%	-0.15%
	Refining-LPG	-1.10%	-1.22%	-1.41%	-1.50%
	Refining-Other	-0.28%	-0.38%	-0.54%	-0.62%
	Petrochemical Manufacturing	-3.02%	-0.74%	-1.12%	-0.37%
	Basic Inorganic Chemical Mfg	-2.00%	-0.49%	-0.36%	-0.12%
	Other Basic Organic Chemical Mfg	-4.59%	-1.31%	-2.61%	-0.85%
	Plastics and Material Resins	-3.20%	-0.84%	-2.53%	-0.82%
	Artificial & Synthetic Fibers, Filaments	-2.12%	-0.18%	-0.86%	-0.30%
	Fertilizers	-3.75%	-0.99%	-1.20%	-0.38%
	Other Chemical & Plastics	-1.05%	-0.11%	-0.91%	-0.30%
	Glass Containers	-1.08%	-0.32%	0.12%	0.04%
	Cement	-4.06%	-1.82%	-0.09%	-0.05%
	Lime and Gypsum	-2.36%	-1.04%	-1.51%	-0.71%
	Mineral Wool	-1.11%	-0.46%	-0.21%	-0.09%
	Other Nonmetallic Mineral	-1.12%	-0.27%	-0.73%	-0.18%
	Iron and Steel Mills and Ferroalloy	-1.56%	-0.28%	-0.19%	-0.06%
	Alumina Refining, Primary & Secondary Aluminum	-4.11%	-1.41%	0.10%	0.02%
	Ferrous Metal Foundries	-0.97%	-0.17%	-0.58%	-0.18%
	Non-Ferrous Metal Foundries	-2.21%	-0.72%	-1.21%	-0.47%
	Other Primary Metals	-1.98%	-0.61%	-0.99%	-0.38%
	Fabricated Metals	-0.33%	-0.11%	-0.26%	-0.16%
	Machinery	-0.96%	-0.41%	-0.73%	-0.35%
	Computer & Electrical Equipment	-0.79%	-0.35%	-0.73%	-0.41%
	Motor Vehicles	-0.89%	-0.19%	-0.87%	-0.36%
	Other Transportation Equipment	-0.79%	-0.27%	-0.62%	-0.25%
	Miscellaneous Manufacturing	-0.83%	-0.38%	-0.98%	-0.60%
Non-Manufacturing Industries	Farms	-0.22%	0.03%	-0.45%	-0.25%
	Forestry, Fishing, etc	0.42%	0.39%	-0.04%	-0.06%
	Oil Mining	-0.42%	-1.73%	-1.42%	-2.68%
	Gas Mining	-1.17%	-2.45%	-1.44%	-2.69%
	Coal Mining	-25.42%	-25.52%	-25.70%	-25.78%
	Other Mining Activities	-0.23%	-0.06%	-0.26%	-0.11%
	Electric Utilities (inc govt enterprises)	-4.26%	-4.24%	-0.81%	-0.92%
	Gas Utilities	-4.30%	-4.40%	-0.90%	-1.03%
	Construction	-0.34%	-0.32%	-0.34%	-0.32%
	Trade	0.28%	0.19%	0.02%	-0.05%
	Air Transportation	-0.53%	-0.28%	-0.81%	-0.56%
	Truck Transportation	-0.21%	-0.09%	-0.42%	-0.30%
	Other Transportation	0.03%	0.06%	-0.23%	-0.18%
	Information	0.19%	0.13%	0.00%	-0.05%
	Finance and Insurance	0.39%	0.29%	0.08%	0.00%
	Real Estate and Rental	0.26%	0.17%	0.02%	-0.06%
	Business Services	0.23%	0.15%	-0.02%	-0.08%
	Other Services	0.37%	0.25%	0.00%	-0.10%
	Govt exc. Electricity	-0.37%	-0.33%	-0.31%	-0.28%

Table 9. Very-Short-Run vs. Short-Run: Effect on Profits Due to a $15/ton CO_2 Tax (Percent Change - No Allocation to EITE Industries)

			Unilateral	Multilateral
		Very-short-run (fixed output)	Short-run	Short-run
Manufacturing Industries	Food	-8.47%	0.06%	0.13%
	Textile	-19.22%	-2.43%	-1.36%
	Apparel	-3.25%	1.79%	1.37%
	Wood & Furniture	-6.66%	-0.60%	-0.34%
	Pulp Mills	-16.39%	-0.41%	-0.04%
	Paper Mills	-9.01%	-0.61%	-0.18%
	Paperboard Mills	-14.89%	-1.05%	-0.42%
	Other Papers	-8.33%	-0.20%	-0.01%
	Refining-LPG	-17.58%	-1.10%	-1.22%
	Refining-Other	-11.81%	-0.28%	-0.38%
	Petrochemical Manufacturing	-14.62%	-3.02%	-0.74%
	Basic Inorganic Chemical Mfg	-31.25%	-2.00%	-0.49%
	Other Basic Organic Chemical Mfg	-84.32%	-4.59%	-1.31%
	Plastics and Material Resins	-33.97%	-3.20%	-0.84%
	Artificial & Synthetic Fibers, Filaments	-64.75%	-2.12%	-0.18%
	Fertilizers	-76.28%	-3.75%	-0.99%
	Other Chemical & Plastics	-4.04%	-1.05%	-0.11%
	Glass Containers	-8.89%	-1.08%	-0.32%
	Cement	-17.05%	-4.06%	-1.82%
	Lime and Gypsum	-13.48%	-2.36%	-1.04%
	Mineral Wool	-6.84%	-1.11%	-0.46%
	Other Nonmetallic Mineral	-9.51%	-1.12%	-0.27%
	Iron and Steel Mills and Ferroalloy	-12.81%	-1.56%	-0.28%
	Alumina Refining, Primary & Secondary Aluminum	-12.55%	-4.11%	-1.41%
	Ferrous Metal Foundries	-6.51%	-0.97%	-0.17%
	Non-Ferrous Metal Foundries	-16.24%	-2.21%	-0.72%
	Other Primary Metals	-7.29%	-1.98%	-0.61%
	Fabricated Metals	-5.35%	-0.33%	-0.11%
	Machinery	-4.51%	-0.96%	-0.41%
	Computer & Electrical Equipment	-5.78%	-0.79%	-0.35%
	Motor Vehicles	-15.91%	-0.89%	-0.19%
	Other Transportation Equipment	-3.25%	-0.79%	-0.27%
	Miscellaneous Manufacturing	-2.61%	-0.83%	-0.38%
Non-Manufacturing Industries	Farms	-2.60%	-0.22%	0.03%
	Forestry, Fishing, etc	-1.19%	0.42%	0.39%
	Oil Mining	-0.53%	-0.42%	-1.73%
	Gas Mining	-0.53%	-1.17%	-2.45%
	Coal Mining	-2.33%	-25.42%	-25.52%
	Other Mining Activities	-2.77%	-0.23%	-0.06%
	Electric Utilities (inc govt enterprises)	-22.38%	-4.26%	-4.24%
	Gas Utilities	-0.85%	-4.30%	-4.40%
	Construction	-2.92%	-0.34%	-0.32%
	Trade	-1.50%	0.28%	0.19%
	Air Transportation	-25.21%	-0.53%	-0.28%
	Truck Transportation	-4.98%	-0.21%	-0.09%
	Other Transportation	-3.26%	0.03%	0.06%
	Information	-0.86%	0.19%	0.13%
	Finance and Insurance	-0.34%	0.39%	0.29%
	Real Estate and Rental	-0.53%	0.26%	0.17%
	Business Services	-1.12%	0.23%	0.15%
	Other Services	-2.14%	0.37%	0.25%
	Govt exc. Electricity	-5.45%	-0.37%	-0.33%

Table 10. Very-Short-Run vs. Short-Run: Effect on Profits Due to a \$15/ton CO_2 Tax with Allocations for EITE Industries (percent change)

			Unilateral	Multilateral
		Very-short-run (fixed output)	Short-run	Short-run
Manufacturing Industries	Food	-6.39%	-0.21%	-0.17%
	Textile	-11.94%	-1.75%	-1.12%
	Apparel	-2.72%	-0.15%	-0.50%
	Wood & Furniture	-4.75%	-0.57%	-0.40%
	Pulp Mills	-3.54%	-0.05%	-0.06%
	Paper Mills	-1.59%	-0.06%	-0.06%
	Paperboard Mills	-7.93%	-0.65%	-0.35%
	Other Papers	-5.40%	-0.26%	-0.15%
	Refining-LPG	-9.34%	-1.41%	-1.50%
	Refining-Other	-6.28%	-0.54%	-0.62%
	Petrochemical Manufacturing	-5.19%	-1.12%	-0.37%
	Basic Inorganic Chemical Mfg	-6.11%	-0.36%	-0.12%
	Other Basic Organic Chemical Mfg	-45.87%	-2.61%	-0.85%
	Plastics and Material Resins	-24.70%	-2.53%	-0.82%
	Artificial & Synthetic Fibers, Filaments	-23.20%	-0.86%	-0.30%
	Fertilizers	-24.11%	-1.20%	-0.38%
	Other Chemical & Plastics	-2.70%	-0.91%	-0.30%
	Glass Containers	-0.23%	0.12%	0.04%
	Cement	-0.66%	-0.09%	-0.05%
	Lime and Gypsum	-8.21%	-1.51%	-0.71%
	Mineral Wool	-1.36%	-0.21%	-0.09%
	Other Nonmetallic Mineral	-5.51%	-0.73%	-0.18%
	Iron and Steel Mills and Ferroalloy	-2.04%	-0.19%	-0.06%
	Alumina Refining, Primary & Secondary Aluminum	-0.05%	0.10%	0.02%
	Ferrous Metal Foundries	-3.42%	-0.58%	-0.18%
	Non-Ferrous Metal Foundries	-8.38%	-1.21%	-0.47%
	Other Primary Metals	-3.37%	-0.99%	-0.38%
	Fabricated Metals	-3.00%	-0.26%	-0.16%
	Machinery	-3.16%	-0.73%	-0.35%
	Computer & Electrical Equipment	-4.25%	-0.73%	-0.41%
	Motor Vehicles	-11.74%	-0.87%	-0.36%
	Other Transportation Equipment	-2.37%	-0.62%	-0.25%
	Miscellaneous Manufacturing	-2.18%	-0.98%	-0.60%
Non-Manufacturing Industries	Farms	-2.13%	-0.45%	-0.25%
	Forestry, Fishing, etc	-1.06%	-0.04%	-0.06%
	Oil Mining	-0.43%	-1.42%	-2.68%
	Gas Mining	-0.43%	-1.44%	-2.69%
	Coal Mining	-2.09%	-25.70%	-25.78%
	Other Mining Activities	-2.41%	-0.26%	-0.11%
	Electric Utilities (inc govt enterprises)	-4.43%	-0.81%	-0.92%
	Gas Utilities	34.44%	-0.90%	-1.03%
	Construction	-2.70%	-0.34%	-0.32%
	Trade	-1.16%	0.02%	-0.05%
	Air Transportation	-24.15%	-0.81%	-0.56%
	Truck Transportation	-4.54%	-0.42%	-0.30%
	Other Transportation	-3.11%	-0.23%	-0.18%
	Information	-0.72%	0.00%	-0.05%
	Finance and Insurance	-0.27%	0.08%	0.00%
	Real Estate and Rental	-0.29%	0.02%	-0.06%
	Business Services	-0.88%	-0.02%	-0.08%
	Other Services	-1.62%	0.00%	-0.10%
	Govt exc. Electricity	-4.41%	-0.31%	-0.28%

Table 11. Effect on Output of a $15/ton CO_2 Tax without H.R. 2454 Allocations (percentage change)

		Unilateral Short-run partial equilibrium	Multilateral Short-run partial equilibrium	Unilateral Medium-run general equilibrium (fixed capital)	Multilateral Medium-run general equilibrium (fixed capital)	Unilateral Long-run general equlibrium (mobile capital)	Multilateral Long-run general equlibrium (mobile capital)
Manufacturing Industries	Food, Beverages, and Tobacco	0.06	0.13	-0.10	-0.07	-0.08	-0.09
	Textiles	-2.43	-1.36	-0.41	-0.42	-0.51	-0.56
	Wearing Apparel and Leather	1.79	1.37	0.00	-0.03	0.09	0.03
	Wood	-0.60	-0.34	-0.33	-0.33	-0.41	-0.48
	Paper and Publishing	-0.36	-0.08	-0.35	-0.24	-0.39	-0.30
	Petroleum and Coal Products	-0.33	-0.43	-6.26	-4.73	-7.28	-6.18
	Chemicals, Rubber, and Plastics	-1.87	-0.38	-1.86	-1.25	-2.38	-1.68
	Non-Metallic Mineral Products	-1.46	-0.47	-1.13	-1.00	-1.41	-1.23
	Ferrous Metals	-1.44	-0.26	-1.34	-1.00	-1.51	-1.11
	Nonferrous primary metals	-2.61	-0.85	-2.01	-1.44	-2.68	-1.92
	Fabricated Metal Products	-0.33	-0.11	-0.49	-0.51	-0.52	-0.56
	Transportation Equipment	-0.86	-0.22	-0.23	-0.25	-0.24	-0.30
	Electronic equipment	-0.79	-0.35	-0.35	-0.44	-0.27	-0.42
	Machinery	-0.96	-0.41	-0.27	-0.38	-0.17	-0.30
	Other Manufacturing	-0.83	-0.38	-0.07	-0.15	0.04	-0.18
Non-Manufacturing Industries	Agriculture	-0.22	0.03	-0.25	-0.18	-0.17	-0.14
	Coal	-25.42	-25.52	-10.02	-13.83	-13.70	-17.03
	Oil mining	-0.42	-1.73	-0.29	-0.39	-1.80	-2.50
	Gas mining	-1.17	-2.45	-0.63	-1.13	-2.33	-3.84
	Other Minerals	-0.23	-0.06	-0.96	-0.78	-1.23	-1.01
	Electric Utilities	-4.26	-4.24	-4.09	-3.64	-4.42	-4.13
	Gas manuf. and distribution	-4.30	-4.40	-6.94	-6.86	-9.16	-9.05
	Construction	-0.34	-0.32	-0.41	-0.40	-0.51	-0.51
	Trade	0.28	0.19	0.01	0.04	-0.03	-0.02
	Transportation Services	-0.15	-0.05	-1.63	-1.29	-1.78	-1.52
	Communications	0.19	0.13	0.14	0.14	0.16	0.15
	Finance and Insurance	0.39	0.29	0.09	0.09	0.06	0.05
	Services (inc real estate)	0.29	0.20	-0.03	-0.02	-0.05	-0.07
	Owner-occupied Dwellings	-	-	0.03	0.03	0.50	0.51
	Weighted average across all EITE[1]: (w/o petroleum products)	-1.02	-0.26	-0.89	-0.63	-1.10	-0.83

[1]Average is across all manufacturing industries that receive at least some allocations under Section 764

Table 12. Effect on Output of a $15/ton CO_2 Tax with H.R. 2454 Allocations (percentage change)

		Unilateral Short-run partial equilibrium effect only	Multilateral Short-run partial equilibrium effect only	Unilateral Medium-run general equilibrium (fixed capital)	Multilateral Medium-run general equilibrium (fixed capital)	Unilateral Long-run general equlibrium (mobile capital)	Multilateral Long-run general equlibrium (mobile capital)
Manufacturing Industries	Food, Beverages, and Tobacco	-0.21	-0.17	-0.10	-0.07	-0.10	-0.11
	Textiles	-1.75	-1.12	-0.37	-0.38	-0.48	-0.53
	Wearing Apparel and Leather	-0.15	-0.50	-0.06	-0.08	-0.06	-0.12
	Wood	-0.57	-0.40	-0.31	-0.31	-0.42	-0.48
	Paper and Publishing	-0.25	-0.15	-0.16	-0.06	-0.16	-0.07
	Petroleum and Coal Products	-0.59	-0.67	-5.66	-4.12	-6.56	-5.45
	Chemicals, Rubber, and Plastics	-1.25	-0.41	-1.28	-0.66	-1.54	-0.83
	Non-Metallic Mineral Products	-0.67	-0.20	-0.60	-0.47	-0.68	-0.51
	Ferrous Metals	-0.27	-0.08	-0.17	0.17	0.02	0.43
	Nonferrous primary metals	-0.72	-0.28	-0.81	-0.23	-0.61	0.16
	Fabricated Metal Products	-0.26	-0.16	-0.36	-0.39	-0.36	-0.40
	Transportation Equipment	-0.79	-0.32	-0.23	-0.26	-0.26	-0.32
	Electronic equipment	-0.73	-0.41	-0.39	-0.49	-0.43	-0.58
	Machinery	-0.73	-0.35	-0.31	-0.43	-0.30	-0.43
	Other Manufacturing	-0.98	-0.60	-0.12	-0.21	-0.10	-0.32
Non-Manufacturing Industries	Agriculture	-0.45	-0.25	-0.29	-0.22	-0.30	-0.26
	Coal	-25.70	-25.78	-8.74	-12.27	-12.07	-15.20
	Oil mining	-1.42	-2.68	-0.26	-0.37	-1.74	-2.44
	Gas mining	-1.44	-2.69	-0.52	-1.02	-2.08	-3.59
	Other Minerals	-0.26	-0.11	-0.50	-0.33	-0.55	-0.33
	Electric Utilities	-0.81	-0.92	-0.92	-0.47	-0.18	0.13
	Gas manuf. and distribution	-0.90	-1.03	-3.65	-3.58	-4.86	-4.76
	Construction	-0.34	-0.32	-0.37	-0.36	-0.44	-0.45
	Trade	0.02	-0.05	0.04	0.07	0.01	0.02
	Transportation Services	-0.39	-0.29	-1.53	-1.19	-1.67	-1.40
	Communications	0.00	-0.05	0.11	0.12	0.11	0.09
	Finance and Insurance	0.08	0.00	0.08	0.09	0.06	0.05
	Services (inc real estate)	0.00	-0.08	-0.06	-0.06	-0.09	-0.10
	Owner-occupied Dwellings	-	-	0.03	0.03	0.35	0.35
	Weighted average across all EITE[1]: (w/o petroleum products)	-0.68	-0.31	-0.54	-0.29	-0.62	-0.35

[1]Average is across all manufacturing industries that receive at least some allocations under Section 764

Table 13a. Medium-Run Trade Effects of a $15/ton CO_2 Tax without H.R. 2454 Allocations

			Unilateral				Multilateral			
		Base case domestic consumption * (million $)	Change in output (percent)	Contribution (Q=U+X-M)			Change in output (percent)	Contribution (Q=U+X-M)		
				Use	Exports	Imports		Use	Exports	Imports
Manufacturing Industries	Food, Beverages, and Tobacco	684.7	-0.10	-0.01	-0.05	0.04	-0.07	0.02	-0.05	0.04
	Textiles	146.8	-0.41	-0.22	-0.11	0.08	-0.42	-0.20	-0.11	0.10
	Wearing Apparel and Leather	159.5	0.00	0.17	-0.02	0.15	-0.03	0.20	-0.03	0.20
	Wood	274.6	-0.33	-0.33	-0.01	-0.02	-0.33	-0.31	-0.02	0.00
	Paper and Publishing	393.8	-0.35	-0.20	-0.10	0.06	-0.24	-0.13	-0.08	0.03
	Petroleum and Coal Products	309.6	-6.26	-6.02	-0.40	-0.16	-4.73	-4.78	-0.31	-0.36
	Chemicals, Rubber, and Plastics	732.8	-1.86	-0.65	-0.86	0.36	-1.25	-0.49	-0.62	0.14
	Non-Metallic Mineral Products	122.8	-1.13	-0.53	-0.27	0.33	-1.00	-0.50	-0.24	0.26
	Ferrous Metals	149.6	-1.34	-0.62	-0.36	0.36	-1.00	-0.61	-0.22	0.17
	Nonferrous primary metals	116.8	-2.01	-0.86	-0.73	0.42	-1.44	-0.74	-0.55	0.15
	Fabricated Metal Products	303.0	-0.49	-0.43	-0.05	0.01	-0.51	-0.43	-0.06	0.02
	Transportation Equipment	765.8	-0.23	-0.18	-0.06	-0.01	-0.25	-0.15	-0.09	0.01
	Electronic equipment	560.9	-0.35	-0.30	-0.09	-0.04	-0.44	-0.32	-0.14	-0.02
	Machinery	862.5	-0.27	-0.40	0.02	-0.12	-0.38	-0.40	-0.07	-0.09
	Other Manufacturing	116.1	-0.07	0.13	-0.06	0.13	-0.15	0.19	-0.11	0.23
Non-Manufacturing Industries	Agriculture	245.5	-0.25	-0.11	-0.12	0.03	-0.18	-0.08	-0.08	0.02
	Coal	38.9	-10.02	-19.43	8.40	-1.01	-13.83	-18.03	3.36	-0.83
	Oil mining	202.5	-0.29	-5.12	0.01	-4.82	-0.39	-3.39	0.00	-3.00
	Gas mining	36.3	-0.63	-8.18	2.50	-5.06	-1.13	-5.83	4.08	-0.62
	Other Minerals	32.0	-0.96	-1.18	0.04	-0.18	-0.78	-0.93	-0.02	-0.16
	Electric Utilities	300.6	-4.09	-3.98	-0.11	0.00	-3.64	-3.56	-0.08	0.00
	Gas manuf. and distribution	86.4	-6.94	-6.97	0.03	0.00	-6.86	-6.86	0.00	0.00
	Construction	1,389.9	-0.41	-0.41	0.00	0.00	-0.40	-0.40	0.00	0.00
	Trade	2,419.5	0.01	0.01	0.00	0.00	0.04	0.04	0.00	0.00
	Transportation Services	788.7	-1.63	-0.90	-0.46	0.27	-1.29	-0.77	-0.34	0.17
	Communications	436.8	0.14	0.13	0.01	0.00	0.14	0.16	-0.01	0.01
	Finance and Insurance	1,728.3	0.09	0.06	0.02	-0.01	0.09	0.09	0.00	0.00
	Services (inc real estate)	6,567.1	-0.03	-0.03	0.00	0.00	-0.02	0.00	-0.02	0.00
	Owner-occupied Dwellings	1,187.8	0.03	0.03	0.00	0.00	0.03	0.03	0.00	0.00

Table 13b. Long Run Trade Effects of a $15/ton CO_2 Tax without H.R. 2454 Allocations

			Unilateral				Multilateral			
		Base case domestic consumption* (million $)	Change in output (percent)	Contribution (Q=U+X-M)			Change in output (percent)	Contribution (Q=U+X-M)		
				Use	Exports	Imports		Use	Exports	Imports
Manufacturing Industries	Food, Beverages, and Tobacco	684.7	-0.07	-0.03	-0.03	0.02	-0.08	-0.02	-0.03	0.03
	Textiles	146.8	-0.43	-0.26	-0.11	0.07	-0.47	-0.26	-0.11	0.09
	Wearing Apparel and Leather	159.5	0.05	0.14	0.00	0.08	0.02	0.14	-0.01	0.12
	Wood	274.6	-0.35	-0.42	0.00	-0.08	-0.40	-0.42	-0.01	-0.04
	Paper and Publishing	393.8	-0.39	-0.25	-0.08	0.05	-0.29	-0.21	-0.07	0.02
	Petroleum and Coal Products	309.6	-6.83	-6.55	-0.46	-0.18	-5.80	-5.89	-0.39	-0.47
	Chemicals, Rubber, and Plastics	732.8	-2.37	-0.83	-1.08	0.46	-1.67	-0.68	-0.81	0.18
	Non-Metallic Mineral Products	122.8	-1.26	-0.62	-0.29	0.35	-1.11	-0.61	-0.25	0.25
	Ferrous Metals	149.6	-1.36	-0.62	-0.37	0.37	-1.00	-0.62	-0.21	0.16
	Nonferrous primary metals	116.8	-2.37	-0.93	-0.88	0.57	-1.70	-0.80	-0.71	0.19
	Fabricated Metal Products	303.0	-0.50	-0.47	-0.04	-0.01	-0.53	-0.50	-0.04	-0.01
	Transportation Equipment	765.8	-0.21	-0.27	-0.02	-0.08	-0.26	-0.27	-0.03	-0.04
	Electronic equipment	560.9	-0.23	-0.30	-0.02	-0.10	-0.35	-0.35	-0.08	-0.09
	Machinery	862.5	-0.16	-0.50	0.13	-0.21	-0.29	-0.52	0.05	-0.18
	Other Manufacturing	116.1	0.02	0.04	0.02	0.03	-0.13	0.07	-0.05	0.15
Non-Manufacturing Industries	Agriculture	245.5	-0.18	-0.11	-0.06	0.01	-0.15	-0.11	-0.03	0.01
	Coal	38.9	-14.31	-20.83	5.61	-0.91	-17.79	-20.12	1.58	-0.75
	Oil mining	202.5	-0.63	-5.68	0.01	-5.04	-0.87	-4.51	0.00	-3.63
	Gas mining	36.3	-1.52	-8.76	1.86	-5.38	-2.51	-7.51	2.15	-2.85
	Other Minerals	32.0	-1.20	-1.37	-0.01	-0.18	-0.98	-1.09	-0.07	-0.18
	Electric Utilities	300.6	-4.43	-4.32	-0.12	0.00	-4.15	-4.06	-0.08	0.00
	Gas manuf. and distribution	86.4	-9.17	-9.16	-0.01	0.00	-9.06	-9.05	-0.01	0.00
	Construction	1,389.9	-0.51	-0.51	0.00	0.00	-0.51	-0.51	0.00	0.00
	Trade	2,419.5	-0.03	-0.04	0.00	0.00	-0.02	-0.02	0.00	0.00
	Transportation Services	788.7	-1.75	-1.02	-0.47	0.26	-1.49	-0.95	-0.37	0.17
	Communications	436.8	0.16	0.13	0.02	-0.01	0.15	0.14	0.01	0.00
	Finance and Insurance	1,728.3	0.06	0.02	0.03	-0.02	0.05	0.03	0.01	-0.01
	Services (inc real estate)	6,567.1	-0.05	-0.08	0.02	-0.01	-0.07	-0.07	0.00	0.00
	Owner-occupied Dwellings	1,187.8	0.50	0.50	0.00	0.00	0.51	0.51	0.00	0.00

Table 14a. Medium-Run Trade Effects of a $15/ton CO_2 Tax with H.R. 2454 Allocations

			Unilateral				Multilateral			
		Base case domestic consumption* (million $)	Change in output (percent)	Contribution (Q=U+X-M)			Change in output (percent)	Contribution (Q=U+X-M)		
				Use	Exports	Imports		Use	Exports	Imports
Manufacturing Industries	Food, Beverages, and Tobacco	684.7	-0.10	0.01	-0.06	0.05	-0.07	0.04	-0.06	0.05
	Textiles	146.8	-0.37	-0.18	-0.10	0.09	-0.38	-0.17	-0.11	0.11
	Wearing Apparel and Leather	159.5	-0.06	0.20	-0.04	0.22	-0.08	0.23	-0.04	0.27
	Wood	274.6	-0.31	-0.27	-0.02	0.01	-0.31	-0.25	-0.03	0.04
	Paper and Publishing	393.8	-0.16	-0.08	-0.05	0.03	-0.06	-0.02	-0.03	0.01
	Petroleum and Coal Products	309.6	-5.66	-5.53	-0.33	-0.19	-4.12	-4.28	-0.24	-0.39
	Chemicals, Rubber, and Plastics	732.8	-1.28	-0.42	-0.61	0.26	-0.66	-0.25	-0.37	0.04
	Non-Metallic Mineral Products	122.8	-0.60	-0.37	-0.12	0.11	-0.47	-0.34	-0.09	0.04
	Ferrous Metals	149.6	-0.17	-0.36	0.06	-0.13	0.17	-0.34	0.20	-0.31
	Nonferrous primary metals	116.8	-0.81	-0.48	-0.23	0.10	-0.23	-0.35	-0.05	-0.17
	Fabricated Metal Products	303.0	-0.36	-0.34	-0.03	-0.01	-0.39	-0.35	-0.04	0.00
	Transportation Equipment	765.8	-0.23	-0.12	-0.08	0.03	-0.26	-0.10	-0.11	0.05
	Electronic equipment	560.9	-0.39	-0.29	-0.12	-0.02	-0.49	-0.31	-0.17	0.00
	Machinery	862.5	-0.31	-0.31	-0.05	-0.05	-0.43	-0.31	-0.14	-0.02
	Other Manufacturing	116.1	-0.12	0.20	-0.11	0.21	-0.21	0.26	-0.16	0.31
Non-Manufacturing Industries	Agriculture	245.5	-0.29	-0.10	-0.15	0.04	-0.22	-0.07	-0.12	0.04
	Coal	38.9	-8.74	-16.97	7.30	-0.93	-12.27	-15.54	2.54	-0.74
	Oil mining	202.5	-0.26	-4.52	0.01	-4.25	-0.37	-2.78	0.00	-2.41
	Gas mining	36.3	-0.52	-6.96	2.08	-4.36	-1.02	-4.55	3.69	0.16
	Other Minerals	32.0	-0.50	-0.64	0.04	-0.11	-0.33	-0.39	-0.02	-0.08
	Electric Utilities	300.6	-0.92	-0.89	-0.04	0.00	-0.47	-0.47	0.00	0.00
	Gas manuf. and distribution	86.4	-3.65	-3.72	0.07	0.00	-3.58	-3.62	0.03	0.00
	Construction	1,389.9	-0.37	-0.37	0.00	0.00	-0.36	-0.36	0.00	0.00
	Trade	2,419.5	0.04	0.04	0.00	0.00	0.07	0.08	-0.01	0.00
	Transportation Services	788.7	-1.53	-0.75	-0.49	0.30	-1.19	-0.62	-0.37	0.20
	Communications	436.8	0.11	0.12	0.00	0.00	0.12	0.15	-0.02	0.01
	Finance and Insurance	1,728.3	0.08	0.08	0.00	0.00	0.09	0.11	-0.01	0.01
	Services (inc real estate)	6,567.1	-0.06	-0.05	-0.01	0.00	-0.06	-0.02	-0.03	0.01
	Owner-occupied Dwellings	1,187.8	0.03	0.03	0.00	0.00	0.03	0.03	0.00	0.00

Table 14b. Long Run Trade Effects of a $15/ton CO_2 Tax with H.R. 2454 Allocations

			Unilateral				Multilateral			
		Base case domestic consumption* (million $)	Change in output (percent)	Contribution (Q=U+X-M)			Change in output (percent)	Contribution (Q=U+X-M)		
				Use	Exports	Imports		Use	Exports	Imports
Manufacturing Industries	Food, Beverages, and Tobacco	684.7	-0.10	-0.01	-0.05	0.04	-0.11	0.00	-0.05	0.05
	Textiles	146.8	-0.40	-0.22	-0.11	0.08	-0.44	-0.22	-0.11	0.11
	Wearing Apparel and Leather	159.5	-0.03	0.18	-0.03	0.18	-0.07	0.19	-0.03	0.22
	Wood	274.6	-0.35	-0.34	-0.02	-0.01	-0.40	-0.34	-0.03	0.03
	Paper and Publishing	393.8	-0.16	-0.11	-0.03	0.02	-0.07	-0.07	-0.01	-0.02
	Petroleum and Coal Products	309.6	-6.15	-5.98	-0.38	-0.21	-5.12	-5.31	-0.31	-0.51
	Chemicals, Rubber, and Plastics	732.8	-1.53	-0.52	-0.71	0.31	-0.83	-0.37	-0.43	0.03
	Non-Metallic Mineral Products	122.8	-0.61	-0.43	-0.10	0.08	-0.45	-0.42	-0.06	-0.02
	Ferrous Metals	149.6	0.01	-0.33	0.13	-0.22	0.38	-0.33	0.29	-0.42
	Nonferrous primary metals	116.8	-0.54	-0.39	-0.11	0.03	0.15	-0.25	0.07	-0.33
	Fabricated Metal Products	303.0	-0.35	-0.38	-0.01	-0.04	-0.38	-0.40	-0.01	-0.03
	Transportation Equipment	765.8	-0.23	-0.19	-0.05	-0.01	-0.28	-0.19	-0.06	0.03
	Electronic equipment	560.9	-0.36	-0.31	-0.09	-0.05	-0.48	-0.36	-0.15	-0.03
	Machinery	862.5	-0.29	-0.39	0.00	-0.10	-0.42	-0.41	-0.08	-0.07
	Other Manufacturing	116.1	-0.07	0.14	-0.06	0.15	-0.22	0.18	-0.12	0.27
Non-Manufacturing Industries	Agriculture	245.5	-0.32	-0.12	-0.16	0.04	-0.28	-0.12	-0.13	0.04
	Coal	38.9	-12.61	-18.39	4.94	-0.84	-15.88	-17.66	1.12	-0.66
	Oil mining	202.5	-0.61	-5.01	0.01	-4.39	-0.85	-3.83	0.00	-2.97
	Gas mining	36.3	-1.36	-7.52	1.55	-4.62	-2.35	-6.24	1.87	-2.03
	Other Minerals	32.0	-0.53	-0.66	0.02	-0.10	-0.32	-0.38	-0.04	-0.10
	Electric Utilities	300.6	-0.18	-0.16	-0.01	0.00	0.13	0.10	0.03	0.00
	Gas manuf. and distribution	86.4	-4.87	-4.91	0.05	0.00	-4.76	-4.80	0.03	0.00
	Construction	1,389.9	-0.45	-0.45	0.00	0.00	-0.45	-0.45	0.00	0.00
	Trade	2,419.5	0.01	0.01	0.00	0.00	0.02	0.03	0.00	0.00
	Transportation Services	788.7	-1.63	-0.83	-0.50	0.30	-1.37	-0.76	-0.40	0.21
	Communications	436.8	0.11	0.10	0.00	0.00	0.09	0.11	-0.01	0.01
	Finance and Insurance	1,728.3	0.06	0.05	0.01	0.00	0.05	0.06	-0.01	0.01
	Services (inc real estate)	6,567.1	-0.09	-0.09	0.00	0.00	-0.11	-0.08	-0.02	0.01
	Owner-occupied Dwellings	1,187.8	0.35	0.35	0.00	0.00	0.35	0.35	0.00	0.00

Table 15. Industry Emission Leakage Due to a $15/ton CO2 Tax in Annex I Countries, without H.R. 2454 Allocations in U.S. (Long Run)

		Change in U.S. Emissions	Change in non-Annex I emissions due to change in net exports to U.S. (1000 tons CO_2)				Leakage rate (%)
			Due to higher exports to US	Due to lower imports from US	Due to differences in Carbon Intensity	Total	
Manufacturing Industries	Food, Beverages, and Tobacco	-7,457	6	11	5	22	0.3
	Textiles	-623	8	6	12	26	4.1
	Wearing Apparel and Leather	-317	4	0	26	30	9.6
	Wood	-889	-7	0	-9	-16	-1.8
	Paper and Publishing	-7,933	16	28	35	79	1.0
	Petroleum and Coal Products	-18,447	443	378	701	1,522	8.2
	Chemicals, Rubber, and Plastics	-14,947	570	658	2,726	3,955	26.5
	Non-Metallic Mineral Products	-10,110	199	79	683	961	9.5
	Ferrous Metals	-4,616	213	78	399	691	15.0
	Nonferrous primary metals	-1,821	116	60	68	245	13.4
	Fabricated Metal Products	-1,010	2	2	9	12	1.2
	Transportation Equipment	-1,434	-2	3	6	7	0.5
	Electronic equipment	-572	-7	3	79	76	13.2
	Machinery	-1,496	-10	-6	18	3	0.2
	Other Manufacturing	-183	7	1	305	312	170.2
Non-Manufacturing Industries	Agriculture	-3,229	7	17	-5	19	
	Coal	-510	-6	-9	-92	-107	
	Oil mining	-2,088	-2,139	-2	828	-1,314	
	Gas mining	-428	-101	-125	-613	-839	
	Other Minerals	-11	0	0	9	9	
	Electric Utilities	-411,572	632	403	227	1,263	
	Gas manuf. and distribution	-6,542	0	1	10	10	
	Construction	-881	0	0	0	0	
	Trade	-5,443	-2	0	-2	-4	
	Transportation Services	-67,547	2,244	1,537	296	4,077	
	Communications	-116	0	0	2	2	
	Finance and Insurance	-827	0	0	-2	-3	
	Services (inc real estate)	-14,895	-3	3	19	19	
	Owner-occupied Dwellings	-	-	-	-	-	

Table 16. Industry Emission Leakage Due to \$15/ton CO_2 Tax in Annex I Countries, with and without H.R. 2454 Allocations in U.S. (Long Run)

			Without Allocations		With Allocations	
		Subsidy rates	Change in U.S. emissions (1000 tons)	Leakage	Change in U.S. emissions (1000 tons)	Leakage
Manufacturing Industries	Food, Beverages, and Tobacco	0.002%	-7,457	0.3%	-6,212	0.6%
	Textiles	0.006%	-623	4.1%	-426	6.4%
	Wearing Apparel and Leather	0.000%	-317	9.6%	-231	16.1%
	Wood	0.011%	-889	-1.8%	-658	-1.1%
	Paper and Publishing	0.167%	-7,933	1.0%	-6,767	0.5%
	Petroleum and Coal Products	0.422%	-18,447	8.2%	-7,422	18.2%
	Chemicals, Rubber, and Plastics	0.248%	-14,947	26.5%	-11,021	27.4%
	Non-Metallic Mineral Products	0.504%	-10,110	9.5%	-8,678	5.9%
	Ferrous Metals	0.912%	-4,616	15.0%	-3,394	-1.1%
	Nonferrous primary metals	0.228%	-1,821	13.4%	-1,116	7.9%
	Fabricated Metal Products	0.000%	-1,010	1.2%	-676	0.6%
	Transportation Equipment	0.000%	-1,434	0.5%	-987	1.4%
	Electronic equipment	0.000%	-572	13.2%	-395	22.3%
	Machinery	0.000%	-1,496	0.2%	-1,041	5.7%
	Other Manufacturing	0.000%	-183	170.2%	-174	188.9%

Table 17. Long-Run Aggregate Effects of Carbon Price Policies (% change)

	Base CO_2 emissions 2004 (mil. tons)	Unilateral US policy		Annex I policy	
		Carbon price only	With output subsidies	Carbon price only	With output subsidies
GDP					
World		-0.02	-0.02	-0.07	-0.07
US		-0.10	-0.09	-0.09	-0.08
Carbon Emissions					
World	25,994	-2.12	-1.73	-4.81	-4.40
US	6,070	-11.49	-9.47	-10.92	-8.88
Canada	566	1.81	1.31	-10.76	-11.10
Mexico	407	0.45	0.36	0.97	0.87
China	4,414	0.48	0.40	1.49	1.42
India	1,059	0.87	0.77	2.97	2.88
Rest of Annex I	7,669	0.70	0.62	-10.19	-10.25
Oil Exporters	1,994	0.77	0.65	2.41	2.28
Rest of the World	3,814	0.91	0.78	2.78	2.65
Carbon Leakage Rate (%)		20.97	21.72	16.96	17.53
Decomposition of U.S. emissions change					
Industry - Input substitution		68.4%	80.8%	69.3%	82.9%
Industry - Output level		20.0%	7.3%	19.2%	5.3%
Household		11.6%	11.9%	11.4%	11.8%
Decompostion of non-policy countries' emissions change					
Industry - Input substitution		58.2%	62.9%	82.2%	80.4%
Industry - Output level		32.4%	27.0%	-0.3%	1.8%
Household		9.5%	10.1%	18.1%	17.8%

Table A1. Value of Industry and Commodity Output from Input-Output Tables - 2006 (billion $)

			Industry output	Commodity output	Domestic commodity consumption
Non-Manufacturing	1	Farms	220	214	211
	2	Forestry, Fishing, etc	40	49	59
	3	Oil Mining	90	75	299
	4	Gas Mining	123	102	123
	5	Coal Mining	26	26	26
	6	Other Mining Activities	158	160	157
	7	Electric Utilities (inc govt enterprises)	372	359	361
	8	Gas Utilities	115	130	130
	9	Construction	1,245	1,330	1,330
Manufacturing Industries	10	Food	581	587	618
	11	Textile	57	51	69
	12	Apparel	29	28	167
	13	Wood & Furniture	159	157	208
	14	Pulp Mills	4	6	6
	15	Paper Mills	51	52	60
	16	Paperboard Mills	23	22	22
	17	Other Papers	179	150	151
	18	Refining-LPG	27	27	27
	19	Refining-Other	452	458	498
	20	Petrochemical Manufacturing	53	64	63
	21	Basic Inorganic Chemical Mfg	26	29	27
	22	Other Basic Organic Chemical Mfg	75	78	67
	23	Plastics and Material Resins	76	76	68
	24	Artificial & Synthetic Fibers and Filaments	9	14	13
	25	Fertilizers	11	12	13
	26	Other Chemical & Plastics	483	478	593
	27	Glass Containers	4	4	5
	28	Cement	10	10	12
	29	Lime and Gypsum	9	9	9
	30	Mineral Wool	6	6	6
	31	Other Nonmetallic Mineral	90	88	103
	32	Iron and Steel Mills and Ferroalloy	83	105	127
	33	Alumina Refining, Primary & Secondary Aluminum	23	22	34
	34	Ferrous Metal Foundries	20	20	20
	35	Non-Ferrous Metal Foundries	13	12	12
	36	Other Primary Metals	46	35	58
	37	Fabricated Metals	280	271	298
	38	Machinery	290	291	321
	39	Computer & Electrical Equipment	419	407	616
	40	Motor Vehicles	351	348	544
	41	Other Transportation Equipment	175	172	122
	42	Miscellaneous Manufacturing	144	141	202
Non-Manufacturing	43	Trade	2,433	2,281	2,151
	44	Air Transportation	145	149	143
	45	Truck Transportation	235	242	219
	46	Other Transportation	400	402	362
	47	Information	1,014	779	754
	48	Finance and Insurance	1,366	1,297	1,274
	49	Real Estate and Rental	2,302	2,383	2,297
	50	Business Services	2,143	2,480	2,398
	51	Other Services	3,014	3,470	3,472
	52	Govt exc. Electricity	2,609	2,150	2,150

Source: Industry output is derived from data obtained from the Bureau of Economic Analysis. Commodity output is based on 2002 relationship between industry/commodity output as found in the 2002 benchmark IO tables. Domestic consumption is based on rebalanced 2006 input-output tables also obtained from the BEA.

Table A2. Value of Energy Commodity Inputs for Industries, 2006 (million $)

		Oil mining	Gas mining	Coal mining	Electric utilities	Gas utilities	Petrolem-lpg	Petroleum-other
Non-Manufacturing	1 Farms	0	0	7	3,381	600	0	10,846
	2 Forestry, Fishing, etc	0	3	0	79	8	0	582
	3 Oil Mining	0	0	14	257	95	0	587
	4 Gas Mining	0	0	20	350	129	0	800
	5 Coal Mining	0	109	0	115	46	0	1,217
	6 Other Mining Activities	0	701	87	767	347	0	9,504
	7 Electric Utilities (inc govt enterprises)	0	29,825	22,865	0	106	0	6,124
	8 Gas Utilities	0	53,482	0	85	0	0	132
	9 Construction	0	0	0	2,219	390	0	26,638
Manufacturing Industries	10 Food	0	159	182	7,601	7,301	0	1,896
	11 Textile	0	49	38	2,326	1,137	0	191
	12 Apparel	0	3	0	216	83	0	9
	13 Wood & Furniture	0	93	21	3,327	952	0	3,086
	14 Pulp Mills	0	4	7	162	138	0	171
	15 Paper Mills	0	54	148	2,975	1,930	0	563
	16 Paperboard Mills	1	41	79	2,029	1,508	0	391
	17 Other Papers	0	58	7	2,732	1,851	0	28
	18 Refining-LPG	16,947	885	6	209	543	0	0
	19 Refining-Other	283,206	14,785	105	3,496	9,069	0	0
	20 Petrochemical Manufacturing	19	1,416	0	433	847	1,803	6,592
	21 Basic Inorganic Chemical Mfg	35	355	28	2,218	29	32	437
	22 Other Basic Organic Chemical Mfg	75	4,028	73	1,975	938	1,234	5,986
	23 Plastics and Material Resins	21	1,572	12	1,758	2,329	12,102	1,855
	24 Artificial & Synthetic Fibers and Filaments	3	179	10	491	61	0	282
	25 Fertilizers	0	678	2	352	1,885	0	24
	26 Other Chemical & Plastics	0	2,132	86	11,681	6,900	1,356	4,368
	27 Glass Containers	0	26	0	352	503	0	8
	28 Cement	0	9	260	1,109	204	0	954
	29 Lime and Gypsum	0	37	89	298	827	0	319
	30 Mineral Wool	0	14	3	379	364	0	0
	31 Other Nonmetallic Mineral	0	107	8	1,839	2,842	0	759
	32 Iron and Steel Mills and Ferroalloy	0	66	525	4,733	3,892	0	245
	33 Alumina Refining, Primary & Secondary Aluminum	0	132	0	4,111	1,095	0	342
	34 Ferrous Metal Foundries	0	5	24	1,145	385	0	295
	35 Non-Ferrous Metal Foundries	0	0	0	422	450	0	0
	36 Other Primary Metals	0	0	15	1,731	781	0	650
	37 Fabricated Metals	0	86	0	3,868	2,508	0	94
	38 Machinery	0	41	1	3,002	853	0	60
	39 Computer & Electrical Equipment	0	40	0	3,733	889	0	283
	40 Motor Vehicles	0	125	4	3,767	1,710	0	224
	41 Other Transportation Equipment	0	61	2	1,508	658	0	90
	42 Miscellaneous Manufacturing	0	10	0	893	154	0	82
Non-Manufacturing	43 Trade	0	1	3	16,208	1,276	0	16,601
	44 Air Transportation	0	0	0	131	6	0	29,418
	45 Truck Transportation	0	0	0	1,590	278	0	23,024
	46 Other Transportation	0	4,072	3	365	105	0	19,931
	47 Information	0	0	0	3,312	1,168	0	2,109
	48 Finance and Insurance	0	0	0	3,584	371	0	1,098
	49 Real Estate and Rental	0	0	6	41,491	1,878	0	6,302
	50 Business Services	0	0	5	12,160	1,777	0	16,531
	51 Other Services	0	1,491	2	25,177	3,799	0	10,914
	52 Govt exc. Electricity	0	7,961	26	20,149	14,056	0	84,347
	C	0	0	1	137,180	36,589	10,536	198,520
	I	-809	-2,438	950	0	0	0	2,594
	G	0	89	0	15,201	11,282	0	0
	X	302	4,115	1,106	2,240	63	0	29,399
	M	-225,173	-24,909	-807	-3,940	0	0	-69,505
	Total Commodity Output	74,627	101,748	26,020	358,968	129,980	27,063	457,994
	Total Domestic Consumption	299,498	122,542	25,722	360,668	129,917	27,063	498,100

Source: Based calculations using BEA input-output data and the EIA's Manufacturing Energy Conumption Survey data.

Table A3. Fuel Inputs from the Manufacturing Energy Consumption Survey (2006)

		Coal (1000 short tons)	Coke and breeze (1,000 short tons)	Residual fuel oil (1,000 bbl)	Distillate fuel oil (1,000 bbl)	Natural gas (billion cubic feet)	LPG and NGL (1,000 bbl)	Electricity (billion kWh)
9	Food	8,130	49	4,613	3,217	660	1,107	82.4
10	Textile	1,704	0	636	95	108	415	25.2
11	Apparel	0	0	40	47	8	69	2.3
12	Wood & Furniture	801	124	636	3,974	101	1,384	36.0
13	Pulp Mills	292	0	1,750	757	13	0	1.8
14	Paper Mills	6,621	0	7,794	473	177	415	32.2
15	Paperboard Mills	3,554	0	4,613	1,135	138	0	22.0
16	Other Papers	292	0	318	95	171	1,246	29.6
17	Refining	4,966	49	9,225	6,244	825	8,027	40.2
18	Petrochemical Manufacturing	0	0	795	189	107	68,641	4.7
19	Basic Inorganic Chemical Mfg	1,120	146	1,432	189	62	2,214	24.0
20	Other Basic Organic Chemical Mfg	3,262	0	318	378	369	85,510	21.4
21	Plastics and Material Resins	536	0	0	189	334	299,474	19.1
22	Artificial & Synthetic Fibers and Filaments	467	0	509	0	42	0	5.3
23	Fertilizers	97	0	0	189	303	0	3.8
24	Other Chemical & Plastics	3,865	0	12,216	946	602	76,313	126.6
25	Glass Containers	0	0	0	63	49	92	3.8
26	Cement	11,441	243	159	568	19	0	12.0
27	Lime and Gypsum	3,797	195	159	378	79	277	3.2
28	Mineral Wool	0	146	0	0	34	0	4.1
29	Other Nonmetallic Mineral	341	0	159	4,667	266	1,015	19.9
30	Iron and Steel Mills and Ferroalloy	12,366	11,197	3,022	568	348	0	51.3
31	Alumina Refining, Primary & Secondary Aluminum	0	0	0	189	121	277	44.5
32	Ferrous Metal Foundries	0	1,065	0	552	34	0	12.4
33	Non-Ferrous Metal Foundries	0	0	0	0	39	0	4.6
34	Other Primary Metals	353	304	0	237	67	346	18.8
35	Fabricated Metals	0	9	0	378	233	1,384	41.9
36	Machinery	49	0	159	378	82	830	32.5
37	Computer & Electrical Equipment	0	0	0	189	85	277	40.4
38	Motor Vehicles	174	0	795	405	173	988	40.8
39	Other Transportation Equipment	70	0	318	162	69	396	16.3
40	Miscellaneous Manufacturing	0	0	40	0	24	277	9.7
	Total Manufacturing Use	64,296	13,528	49,706	26,853	5,742	550,973	832.9

Note: These values are for the combusted fuels, not all purpose or consumed fuels.

Source: Based on data from the EIA's Manufacturing Energy Consumption Survey.

Table A4. Total Coal/Coke and Crude Oil Consumption and Combustion

		Coal and coke (million short tons)		Crude oil (million bbl)	
		Total consumption	Combusted	Total consumption	Combusted
1	Farms	0.3	0.3	0.0	0.0
2	Forestry, Fishing, etc	0.0	0.0	0.0	0.0
3	Oil Mining	0.6	0.6	0.0	0.0
4	Gas Mining	0.9	0.9	0.0	0.0
5	Coal Mining	0.0	0.0	0.0	0.0
6	Other Mining Activities	3.9	3.9	0.0	0.0
7	Electric Utilities (inc govt enterprises)	1,026.6	1,026.6	0.0	0.0
8	Gas Utilities	0.0	0.0	0.0	0.0
9	Construction	0.0	0.0	0.0	0.0
10	Food	8.2	8.2	0.0	0.0
11	Textile	1.7	1.7	0.0	0.0
12	Apparel	0.0	0.0	0.0	0.0
13	Wood & Furniture	0.9	0.9	0.0	0.0
14	Pulp Mills	0.3	0.3	0.0	0.0
15	Paper Mills	6.6	6.6	0.0	0.0
16	Paperboard Mills	3.6	3.6	0.0	0.0
17	Other Papers	0.3	0.3	0.0	0.0
18	Refining-LPG	0.3	0.1	419.7	26.5
19	Refining-Other	4.7	2.5	7,014.2	442.9
20	Petrochemical Manufacturing	0.0	0.0	0.5	0.5
21	Basic Inorganic Chemical Mfg	1.3	1.1	0.9	0.9
22	Other Basic Organic Chemical Mfg	3.3	2.6	1.9	1.9
23	Plastics and Material Resins	0.5	0.5	0.5	0.5
24	Artificial & Synthetic Fibers and Filaments	0.5	0.5	0.1	0.1
25	Fertilizers	0.1	0.1	0.0	0.0
26	Other Chemical & Plastics	3.9	3.8	0.0	0.0
27	Glass Containers	0.0	0.0	0.0	0.0
28	Cement	11.7	11.7	0.0	0.0
29	Lime and Gypsum	4.0	4.0	0.0	0.0
30	Mineral Wool	0.1	0.1	0.0	0.0
31	Other Nonmetallic Mineral	0.3	0.3	0.0	0.0
32	Iron and Steel Mills and Ferroalloy	23.6	22.7	0.0	0.0
33	Alumina Refining, Primary & Secondary Aluminum	0.0	0.0	0.0	0.0
34	Ferrous Metal Foundries	1.1	1.1	0.0	0.0
35	Non-Ferrous Metal Foundries	0.0	0.0	0.0	0.0
36	Other Primary Metals	0.7	0.4	0.0	0.0
37	Fabricated Metals	0.0	0.0	0.0	0.0
38	Machinery	0.0	0.0	0.0	0.0
39	Computer & Electrical Equipment	0.0	0.0	0.0	0.0
40	Motor Vehicles	0.2	0.2	0.0	0.0
41	Other Transportation Equipment	0.1	0.1	0.0	0.0
42	Miscellaneous Manufacturing	0.0	0.0	0.0	0.0
43	Trade	0.1	0.1	0.0	0.0
44	Air Transportation	0.0	0.0	0.0	0.0
45	Truck Transportation	0.0	0.0	0.0	0.0
46	Other Transportation	0.1	0.1	0.0	0.0
47	Information	0.0	0.0	0.0	0.0
48	Finance and Insurance	0.0	0.0	0.0	0.0
49	Real Estate and Rental	0.3	0.3	0.0	0.0
50	Business Services	0.2	0.2	0.0	0.0
51	Other Services	0.1	0.1	0.0	0.0
52	Govt exc. Electricity	1.2	1.2	0.0	0.0

Source: Based on the EIA's Manufacturing Energy Consumption Survey and authors' calculations.

Table A5. Total Consumption and Combusted Fuel: Refining-LPG and Refining-Other (million bbl)

		Refining-LPG		Refining-Other	
		Total consumption	Combusted	Total consumption	Combusted
1	Farms	0.0	0.0	159.2	126.4
2	Forestry, Fishing, etc	0.0	0.0	8.5	6.8
3	Oil Mining	0.0	0.0	8.6	6.8
4	Gas Mining	0.0	0.0	11.7	9.3
5	Coal Mining	0.0	0.0	17.9	14.2
6	Other Mining Activities	0.0	0.0	139.5	110.8
7	Electric Utilities (inc govt enterprises)	0.0	0.0	89.9	71.4
8	Gas Utilities	0.0	0.0	1.9	1.5
9	Construction	0.0	0.0	391.0	310.5
10	Food	0.0	0.0	27.8	27.7
11	Textile	0.0	0.0	2.8	2.8
12	Apparel	0.0	0.0	0.1	0.1
13	Wood & Furniture	0.0	0.0	45.3	44.2
14	Pulp Mills	0.0	0.0	2.5	2.5
15	Paper Mills	0.0	0.0	8.3	8.3
16	Paperboard Mills	0.0	0.0	5.7	5.7
17	Other Papers	0.0	0.0	0.4	0.4
18	Refining-LPG	20.4	20.4	0.0	0.0
19	Refining-Other	341.4	341.4	0.0	0.0
20	Petrochemical Manufacturing	70.6	0.0	96.8	96.5
21	Basic Inorganic Chemical Mfg	2.3	0.0	6.4	5.2
22	Other Basic Organic Chemical Mfg	89.5	0.0	87.9	71.0
23	Plastics and Material Resins	300.9	1.7	27.2	22.9
24	Artificial & Synthetic Fibers and Filaments	0.0	0.0	4.1	3.1
25	Fertilizers	0.0	0.0	0.4	0.2
26	Other Chemical & Plastics	79.5	1.7	64.1	15.1
27	Glass Containers	0.0	0.0	0.1	0.1
28	Cement	0.0	0.0	14.0	14.0
29	Lime and Gypsum	0.0	0.0	4.7	4.7
30	Mineral Wool	0.0	0.0	0.0	0.0
31	Other Nonmetallic Mineral	0.0	0.0	11.1	9.0
32	Iron and Steel Mills and Ferroalloy	0.0	0.0	3.6	3.6
33	Alumina Refining, Primary & Secondary Aluminum	0.0	0.0	5.0	0.5
34	Ferrous Metal Foundries	0.0	0.0	4.3	3.8
35	Non-Ferrous Metal Foundries	0.0	0.0	0.0	0.0
36	Other Primary Metals	0.0	0.0	9.5	1.6
37	Fabricated Metals	0.0	0.0	1.4	1.3
38	Machinery	0.0	0.0	0.9	0.9
39	Computer & Electrical Equipment	0.0	0.0	4.2	0.5
40	Motor Vehicles	0.0	0.0	3.3	3.2
41	Other Transportation Equipment	0.0	0.0	1.3	1.3
42	Miscellaneous Manufacturing	0.0	0.0	1.2	1.2
43	Trade	0.0	0.0	243.7	193.5
44	Air Transportation	0.0	0.0	431.9	342.9
45	Truck Transportation	0.0	0.0	338.0	268.4
46	Other Transportation	0.0	0.0	292.6	232.3
47	Information	0.0	0.0	31.0	24.6
48	Finance and Insurance	0.0	0.0	16.1	12.8
49	Real Estate and Rental	0.0	0.0	92.5	73.5
50	Business Services	0.0	0.0	242.7	192.7
51	Other Services	0.0	0.0	160.2	127.2
52	Govt exc. Electricity	0.0	0.0	1,019.6	809.6

Source: Based on the EIA's Manufacturing Energy Consumption Survey and authors' calculations.

Table A6. Total Consumption and Combusted Fuel: Natural Gas and Electricity

		Natural gas (billion cubic feet)		
		Total consumption	Combusted	Electricity consumption (billion kWh)
1	Farms	51.5	51.5	37
2	Forestry, Fishing, etc	1.4	1.4	1
3	Oil Mining	8.1	8.1	3
4	Gas Mining	11.1	11.1	4
5	Coal Mining	26.6	26.6	1
6	Other Mining Activities	175.9	175.9	8
7	Electric Utilities (inc govt enterprises)	6,231.2	6,231.2	0
8	Gas Utilities	11,157.2	0.0	1
9	Construction	33.4	33.4	24
10	Food	659.9	659.6	82
11	Textile	107.9	107.9	25
12	Apparel	7.8	7.8	2
13	Wood & Furniture	101.1	100.8	36
14	Pulp Mills	12.6	12.6	2
15	Paper Mills	176.9	176.9	32
16	Paperboard Mills	138.0	138.0	22
17	Other Papers	171.0	170.7	30
18	Refining-LPG	46.6	46.6	2
19	Refining-Other	778.5	778.5	38
20	Petrochemical Manufacturing	106.9	106.9	5
21	Basic Inorganic Chemical Mfg	62.2	54.4	24
22	Other Basic Organic Chemical Mfg	369.3	297.4	21
23	Plastics and Material Resins	334.3	323.6	19
24	Artificial & Synthetic Fibers and Filaments	42.5	35.2	5
25	Fertilizers	303.2	302.9	4
26	Other Chemical & Plastics	601.8	538.1	127
27	Glass Containers	48.6	48.6	4
28	Cement	19.4	19.4	12
29	Lime and Gypsum	78.7	78.7	3
30	Mineral Wool	34.0	34.0	4
31	Other Nonmetallic Mineral	266.3	266.3	20
32	Iron and Steel Mills and Ferroalloy	347.9	316.8	51
33	Alumina Refining, Primary & Secondary Aluminum	121.5	121.5	45
34	Ferrous Metal Foundries	34.0	34.0	12
35	Non-Ferrous Metal Foundries	38.6	38.6	5
36	Other Primary Metals	67.1	67.1	19
37	Fabricated Metals	233.2	233.0	42
38	Machinery	81.6	81.6	33
39	Computer & Electrical Equipment	84.5	84.3	40
40	Motor Vehicles	172.8	172.8	41
41	Other Transportation Equipment	69.2	69.2	16
42	Miscellaneous Manufacturing	15.2	15.2	10
43	Trade	109.6	109.6	176
44	Air Transportation	0.5	0.5	1
45	Truck Transportation	23.8	23.8	17
46	Other Transportation	858.5	858.5	4
47	Information	100.3	100.3	36
48	Finance and Insurance	31.8	31.8	39
49	Real Estate and Rental	161.2	161.2	450
50	Business Services	152.5	152.5	132
51	Other Services	637.3	637.3	273
52	Govt exc. Electricity	2,867.4	2,867.4	218

Source: Based on the EIA's Manufacturing Energy Consumption Survey and authors' calculations.

Table A7. CO_2 Emissions; Direct Combustion of Fossil Fuels and Indirect from Electricity (Metric Tons)

		Total emissions	Direct combustion	Due to electricity
1	Farms	77.65	53.60	24.05
2	Forestry, Fishing, etc	3.19	2.77	0.42
3	Oil Mining	6.43	4.41	2.01
4	Gas Mining	8.76	6.02	2.74
5	Coal Mining	8.18	7.09	1.09
6	Other Mining Activities	66.78	61.19	5.59
7	Electric Utilities (inc govt enterprises)	2,362.71	2,362.71	0.00
8	Gas Utilities	1.18	0.61	0.57
9	Construction	139.43	125.08	14.34
10	Food	115.53	62.95	52.58
11	Textile	25.37	10.32	15.05
12	Apparel	1.72	0.48	1.24
13	Wood & Furniture	46.74	24.85	21.89
14	Pulp Mills	3.35	2.25	1.09
15	Paper Mills	44.92	25.81	19.10
16	Paperboard Mills	29.65	16.73	12.91
17	Other Papers	28.76	10.05	18.72
18	Refining-LPG	20.63	19.20	1.43
19	Refining-Other	344.76	320.88	23.88
20	Petrochemical Manufacturing	47.48	44.37	3.11
21	Basic Inorganic Chemical Mfg	22.38	7.57	14.81
22	Other Basic Organic Chemical Mfg	64.69	50.34	14.35
23	Plastics and Material Resins	41.57	28.45	13.12
24	Artificial & Synthetic Fibers and Filaments	7.12	4.08	3.04
25	Fertilizers	19.27	16.85	2.41
26	Other Chemical & Plastics	122.51	43.19	79.32
27	Glass Containers	4.94	2.71	2.24
28	Cement	37.10	29.31	7.79
29	Lime and Gypsum	16.10	13.91	2.18
30	Mineral Wool	4.98	2.14	2.83
31	Other Nonmetallic Mineral	31.27	18.80	12.47
32	Iron and Steel Mills and Ferroalloy	101.70	62.89	38.81
33	Alumina Refining, Primary & Secondary Aluminum	39.02	6.85	32.17
34	Ferrous Metal Foundries	14.37	5.45	8.93
35	Non-Ferrous Metal Foundries	5.44	2.11	3.33
36	Other Primary Metals	17.59	5.05	12.54
37	Fabricated Metals	40.39	13.28	27.12
38	Machinery	26.25	4.91	21.34
39	Computer & Electrical Equipment	27.00	4.80	22.20
40	Motor Vehicles	42.55	11.05	31.50
41	Other Transportation Equipment	14.40	4.42	9.97
42	Miscellaneous Manufacturing	6.91	1.31	5.60
43	Trade	186.00	83.08	102.92
44	Air Transportation	136.93	136.14	0.78
45	Truck Transportation	119.06	107.84	11.22
46	Other Transportation	141.72	139.44	2.28
47	Information	34.90	15.24	19.65
48	Finance and Insurance	28.79	6.83	21.95
49	Real Estate and Rental	288.90	38.51	250.39
50	Business Services	161.72	85.30	76.42
51	Other Services	248.05	85.50	162.55
52	Govt exc. Electricity	613.09	480.47	132.62
	Government	154.05	53.99	100.05
	Consumption	2,052.75	1,149.83	902.91
	Total	8,256.68	5,883.03	2,373.66

Source: Based on the EIA's Manufacturing Energy Consumption Survey and authors' calculations.

Table A8. Primary CO_2 Emissions Intensity and Total including Electricity (Metric Tons/million $)

		Total CO_2 intensity	Primary CO_2 intensity
1	Farms	344.6	243.5
2	Forestry, Fishing, etc	82.7	69.6
3	Oil Mining	67.9	49.1
4	Gas Mining	67.9	49.1
5	Coal Mining	300.2	271.2
6	Other Mining Activities	418.0	386.1
7	Electric Utilities (inc govt enterprises)	6,346.4	6,346.4
8	Gas Utilities	240.7	5.3
9	Construction	112.2	100.5
10	Food	194.5	108.4
11	Textile	449.2	180.9
12	Apparel	65.1	16.3
13	Wood & Furniture	293.2	155.8
14	Pulp Mills	801.0	543.4
15	Paper Mills	883.9	502.6
16	Paperboard Mills	1,296.4	721.0
17	Other Papers	156.3	56.0
18	Refining-LPG	760.4	709.5
19	Refining-Other	760.8	709.9
20	Petrochemical Manufacturing	897.6	843.4
21	Basic Inorganic Chemical Mfg	863.4	294.9
22	Other Basic Organic Chemical Mfg	847.8	673.8
23	Plastics and Material Resins	523.3	372.0
24	Artificial & Synthetic Fibers and Filaments	858.6	479.3
25	Fertilizers	1,733.2	1,523.9
26	Other Chemical & Plastics	248.5	89.4
27	Glass Containers	1,141.9	615.4
28	Cement	8,083.3	2,843.9
29	Lime and Gypsum	3,617.9	1,555.0
30	Mineral Wool	721.1	333.5
31	Other Nonmetallic Mineral	345.2	210.0
32	Iron and Steel Mills and Ferroalloy	1,128.5	754.6
33	Alumina Refining, Primary & Secondary Aluminum	1,479.6	298.9
34	Ferrous Metal Foundries	647.5	271.7
35	Non-Ferrous Metal Foundries	390.5	168.6
36	Other Primary Metals	354.9	109.0
37	Fabricated Metals	138.3	47.4
38	Machinery	84.9	16.9
39	Computer & Electrical Equipment	70.2	11.5
40	Motor Vehicles	102.2	31.5
41	Other Transportation Equipment	81.9	25.2
42	Miscellaneous Manufacturing	49.7	9.0
43	Trade	78.0	34.2
44	Air Transportation	947.5	941.5
45	Truck Transportation	503.8	459.2
46	Other Transportation	354.9	348.9
47	Information	36.5	15.0
48	Finance and Insurance	22.3	5.0
49	Real Estate and Rental	135.4	16.7
50	Business Services	77.2	39.8
51	Other Services	83.3	28.4
52	Govt exc. Electricity	235.0	184.2

Source: Based on the EIA's Manufacturing Energy Consumption Survey, BEA industry output data and authors' calculations.

Table B1. Output Demand Elasticities

	Sectors	Annex 1 policy	Unilateral policy
1	Farms	-0.369	-0.765
2	Forestry, Fishing, etc	-0.369	-0.765
3	Oil Mining	-0.170	-0.111
4	Gas Mining	-0.301	-0.171
5	Coal Mining	-0.426	-0.161
6	Other Mining Activities	-0.147	-0.348
7	Electric Utilities (inc govt enterprises)	-0.505	-0.518
8	Gas Utilities	-0.530	-0.530
9	Construction	-0.712	-0.715
10	Food	-0.349	-0.588
11	Textile	-1.082	-1.775
12	Apparel	-1.700	-2.288
13	Wood & Furniture	-0.729	-1.124
14	Pulp Mills	-0.294	-0.585
15	Paper Mills	-0.294	-0.585
16	Paperboard Mills	-0.294	-0.585
17	Other Papers	-0.294	-0.585
18	Refining-LPG	-0.071	-0.071
19	Refining-Other	-0.071	-0.071
20	Petrochemical Manufacturing	-0.462	-1.424
21	Basic Inorganic Chemical Mfg	-0.462	-1.424
22	Other Basic Organic Chemical Mfg	-0.462	-1.424
23	Plastics and Material Resins	-0.462	-1.424
24	Artificial & Synthetic Fibers and Filaments	-0.462	-1.424
25	Fertilizers	-0.462	-1.424
26	Other Chemical & Plastics	-0.462	-1.424
27	Glass Containers	-0.362	-0.767
28	Cement	-0.362	-0.767
29	Lime and Gypsum	-0.362	-0.767
30	Mineral Wool	-0.362	-0.767
31	Other Nonmetallic Mineral	-0.362	-0.767
32	Iron and Steel Mills and Ferroalloy	-0.288	-0.912
33	Alumina Refining, Primary & Secondary Aluminum	-0.733	-1.901
34	Ferrous Metal Foundries	-0.288	-0.912
35	Non-Ferrous Metal Foundries	-0.733	-1.901
36	Other Primary Metals	-0.733	-1.901
37	Fabricated Metals	-0.385	-0.717
38	Machinery	-0.873	-1.814
39	Computer & Electrical Equipment	-1.484	-2.733
40	Motor Vehicles	-0.737	-1.828
41	Other Transportation Equipment	-0.737	-1.828
42	Miscellaneous Manufacturing	-1.539	-2.636
43	Trade	-0.422	-0.438
44	Air Transportation	-0.347	-0.550
45	Truck Transportation	-0.347	-0.550
46	Other Transportation	-0.347	-0.550
47	Information	-0.364	-0.421
48	Finance and Insurance	-0.370	-0.438
49	Real Estate and Rental	-0.602	-0.672
50	Business Services	-0.602	-0.672
51	Other Services	-0.602	-0.672
52	Govt exc. Electricity	-0.602	-0.672

Table B2 - Overview of Corrections for Double-Counting in Energy Data for Iron and Steel Mills
Iron and Steel Mills - MECS Data - trillion BTU (2006)

	Total	Electricity	Residual Fuel Oil	Distillate Fuel Oil	Natural Gas	LPG/NGL	Coal	Coke and Breeze	Other	Shipments of Energy Produced Onsite
All-Purpose Use of Energy	1,019	175	19	3	337	*	360	230	39	145
Feedstock Use of Energy	431	-	0	*	32	*	345	44	9	
Non-Feedstock Use of Energy	1,125	175	19	3	305	*	14	344	265	
Step 1: Assumption that feedstock use of Coal is converted to Coke										
All-Purpose Use of Energy	1,019	175	19	3	337	*	360	230	39	
Feedstock Use of Energy	431	-	0	*	32	*	**x**	44	9	
Non-Feedstock Use of Energy	1,125	175	19	3	305	*	14	344	265	
Step 2: Combine 'Other' category with Coal consumption										
All-Purpose Use of Energy	1,019	175	19	3	337	*	**254**	230	0	
Feedstock Use of Energy	431	-	0	*	32	*	**9**	44	0	
Non-Feedstock Use of Energy	1,125	175	19	3	305	*	14	344	0	
Step 3: Non-feedstock use of Coal calculated as residual of all-purpose and feedstock use of energy										
All-Purpose Use of Energy	1,019	175	19	3	337	*	254	230	0	
Feedstock Use of Energy	431	-	0	*	32	*	9	44	0	
Non-Feedstock Use of Energy	1,125	175	19	3	305	*	**245**	344	0	
Step 4: Consumption labeled as * is replaced with 0s										
All-Purpose Use of Energy	1,019	175	19	3	337	**0**	254	230	0	
Feedstock Use of Energy	431	**0**	0	**0**	32	**0**	9	44	0	
Non-Feedstock Use of Energy	1,125	175	19	3	305	**0**	245	344	0	
Step 5: Removal of over-counting in non-feedstock component of Coke and Breeze consumption										
All-Purpose Use of Energy	1,019	175	19	3	337	**0**	254	230	0	
Feedstock Use of Energy	431	**0**	0	**0**	32	**0**	9	44	0	
Non-Feedstock Use of Energy	1,125	175	19	3	305	**0**	245	**186**	0	