NATIONAL CENTER FOR ENVIRONMENTAL ECONOMICS

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Working Paper Series

Working Paper # 12-03
May, 2012

U.S. Environmental Protection Agency
National Center for Environmental Economics
1200 Pennsylvania Avenue, NW (MC 1809)
Washington, DC 20460
http://www.epa.gov/economics

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April 26, 2012

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 offsetting policies to compensate losers and the number of countries implementing comparable policies. We examine the effects of a $15/ton CO_2 price, including Waxman-Markey-type allocations, on a disaggregated set of 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 energy-intensive trade-exposed (EITE) industries will be substantial. When output prices can rise to reflect higher energy costs, the reduction in profits is substantially smaller, and the offsetting policies in H.R. 2454 reduce output and profit losses even more. Over the medium- and long-terms, however, when more adjustments occur, the impact on output is more varied due to general equilibrium effects. We find that the use of the output-based rebates and other allocations in H.R. 2454 can substantially offset the output losses over all four time frames considered. Trade or "competitiveness" effects from the carbon price explain a significant portion of the fall in output for EITE sectors, but in absolute terms the trade impacts are modest and can be reduced or even reversed with the subsidies. The subsidies are less effective, however, in preventing emissions leakage to countries not adopting carbon policies. Roughly half of U.S. trade-related leakage to non-policy countries can be explained by changes in the volume of trade and the other half by higher emissions intensities induced by lower world fuel prices.

Key Words: Carbon price, competitiveness, input-output analysis, computable general equilibrium models, output-based allocations, carbon leakage.

Subject Areas: Economic Impacts, Modeling.

JEL Classification Codes: F14, D 21, D57, D58, H23.

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I. Introduction

Despite the failure to enact cap and trade legislation in the 111th Congress, analysis of the specific proposals advanced in the debate can provide important lessons for the future consideration of economy-wide carbon pricing, via either cap and trade or taxation. In whatever form it takes, pricing carbon emissions will not only adversely affect electricity and primary energy producers, but may also 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.

The most effective approach to reduce the disproportionate impacts of domestic carbon pricing is to ensure comparable action by other countries. In the absence of global action, the U.S. Congress has considered proposals to reduce the 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 prescribed, for example, in the House-passed American Clean Energy and Security Act of 2009 (H.R. 2454), firms would be able to maintain sales 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. Most of these analyses assume fully mobile factors in which workers and producers are assumed to shift seamlessly between sectors. Such long-run studies, however, fail to capture the short-run impacts of carbon pricing policies or the reality that available mitigation options will change over time. A steel mill faced with higher energy costs cannot immediately and costlessly 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.[1]

This paper advances the study of competitiveness and leakage issues by examining the impacts of domestic carbon pricing policies on a highly disaggregated set of industries over multiple timeframes, with special focus on the suite of subsidies to vulnerable industries contained in H.R. 2454. This includes the output-based rebates for EITE industries to lessen adverse impacts and the special treatment of the refining sector as well as electricity and gas local distribution companies (LDCs). We do not analyze the effects of the border adjustments scheduled to begin in 2020 under the legislation. The revenues raised by the cap and trade system that are not explicitly allocated to these sectors are returned to households to partially offset the higher prices as envisaged in these proposals. 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, when output prices cannot be changed but input prices rise and profits fall accordingly;
- the short-run, when output prices can rise to reflect the higher energy costs, with a corresponding fall 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 between sectors.

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. While this may seem unrealistic, it results in the maximum possible impact on profits. The second horizon allows for higher output prices by incorporating 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 (described below), which enables us to capture the effect of customers switching to other products, including substitution to similar imported commodities.

[1] Dynamic general equilibrium models do take some time-relevant adjustments into account, although such models are usually highly aggregated and generally ignore potentially important differences among major energy-consuming sectors.

We analyze the third and fourth time horizons with a CGE model based on the GTAP 7 database. 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 and directly lower the demand for both. In addition, a lower demand for plastic indirectly lowers the chemical industry's demand for steel. These kinds of 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, long-run analysis allows for full capital mobility. Instead of industry-specific profit effects, capital is reallocated so that it earns the same economy-wide return in all sectors. 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 energy-intensive products. This switch in final demand changes the structure of production and total energy consumption, and changes the cost of capital relative to labor.[2]

The four horizons considered in this paper can be summarized in the following table:

	Very-Short-Run	Short-Run	Medium-Run	Long-Run
Input price effects	X	X	X	X
Demand adjustments		X	X	X
Input substitution			X	X
Sectoral capital mobility				X

This four horizon 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 over time, thereby dampening the initial price shock and decline in sales. On the other hand, the consumers of such energy-intensive goods also are gradually substituting toward alternative inputs and capital and reducing the quantities demanded. The net effect of these long-run adjustments is not clear a priori. Indeed, our results show that both influences are at work.

Assumptions about climate policies adopted in other countries are also clearly important in understanding competitiveness and leakage issues. Although we present some results for the case of

[2] While the "long-run" may be defined in a variety of ways, our definition 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.

unilateral U.S. action, our principal analysis assumes comparable actions in other Annex I nations, which account for roughly half of U.S. trade in energy-intensive goods. We examine leakage of U.S. emissions that are due to changes in trade with countries that are not undertaking carbon pricing policies, and also due to increased fossil fuel consumption in these same countries that now face lower fuel prices because of reduced demand in Annex I.

The focus of this paper is on a sequence of 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 output, profits, and trade and leakage effects. Following this introduction, Section II reviews a number of previous studies that have examined competitiveness issues surrounding carbon pricing at a detailed, industry-specific level. We particularly focus on the analyses that have incorporated output-based rebate mechanisms of the type contained in H.R. 2454. Section III describes the basic modeling approaches and data sources. Section IV describes output-based rebates and other targeted allowance allocations to vulnerable industries under H.R. 2454. Section V describes the principal results for output and profits across multiple time horizons. Section VI addresses trade and leakage impacts. Section VII offers some overall conclusions.

II. Other Studies with Detailed Industry Impacts

The literature on industry impacts of carbon policies is based largely on simulation modeling, although a number of papers involve direct econometric estimation, e.g. Aldy and Pizer (2011). 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 papers by Fischer and Fox (2007, 2009), 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 more 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 static CGE model based on GTAP 6 data (2001 base year), they report impacts on 18 non-energy 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 most industries examined. 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 estimate an aggregate leakage of 12–15 percent, that is, the share of total U.S. emissions reductions that are offset by increases in the rest of the world. At the industry level, the implied leakage rate for the energy-intensive industries is on the order of 40–45 percent.[3]

An assessment by the U.S. Energy Information Administration (EIA), 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 U.S. Environmental Protection Agency (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, the models used by the EIA and EPA do not disaggregate industry impacts to any significant extent.

An interagency report on the competitiveness impacts of H.R. 2454 conducted by multiple executive branch agencies (EPA 2009b), uses on an updated version of the Fischer-Fox (2007) model. 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. For three of the five sectors analyzed, the combined effect of the direct allocations to EITEs, plus those to LDCs, offset virtually all of the incremental costs associated with the carbon pricing. For two sectors—chemicals and plastics; pulp, paper, and print—the allocations actually 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 those to LDCs. For the five 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: 1) changes in trade flows and 2) global substitutions in production processes associated with changing fuel and raw material prices induced by the domestic carbon policy. Fischer and Fox (2007, 2009), and Boehringer et. al (2010) find the latter to be a significant source of emissions leakage. However, because trade flows are more readily influenced by policy measures than global fuel or resource substitutions, and because they are an important proxy for domestic output and employment losses, the interagency report focuses solely on trade flows as the metric of impacts.

Although the European Union 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

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

specific industries in the European Union. Demailly and Quirion (2006) find that if EU 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 to 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 models developed in this paper are based on a fixed coefficient, input–output (I-O) framework of the U.S. economy, disaggregated to 52 NAICS industries (listed in Table 2). Alternatively, we could have imposed appropriate constraints on the CGE model to simulate the more inflexible conditions represented in the very-short- and short-runs, but we would not have been able to conduct the analysis at a sufficient level of industry disaggregation (a limitation of all the simulation models discussed in the previous section). 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 method that explicitly recognizes that some fuel inputs are not combusted but converted to other products and hence should not be subject to the CO_2 price. The details of our methodology are given in Adkins et al. (2010). Two cases are considered, one without the H.R. 2454 subsidies in the U.S. and one with them. The starting point for the analysis is the value data for industry output and intermediate inputs for the 65 industries in the 2006 annual U.S. I-O tables (BEA 2008), supplemented by details from the 427 industries in the 2002 benchmark I-O tables.

To compute the carbon emissions from combustion and electricity use in each industry, we rely on multiple data sets, including the *Annual Energy Review* (EIA 2009c), the *Manufacturing Energy Consumption Survey* (EIA 2006), and the I-O value totals. Process emissions from 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, are also included.[4] 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 demand elasticities. In the absence of comprehensive, consistent estimates of such elasticities for all industries, we simulate them using our CGE model, described below.

To estimate the demand elasticity for each industry, we simulate a one percent tax on that industry's output and record the resulting 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

[4] A detailed description of the data construction is given in Appendix B of Adkins et al. (2010). Process emissions are taken from Table 15 of EIA 2009b.

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).

H.R. 2454 has provisions to return the revenue from the sales of permits back to households, that is, the revenue left over after providing for the rebates to the LDCs and 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 indefinitely? If the latter, do they change the spending habits within our "short-run" horizon? Since the carbon prices and transfers are part of a long-run policy horizon that lasts many years into the future, we make the simple assumption that all of the transfers will be spent in the short-run. For the short-run horizon we adopt a "partial equilibrium" approach, where the change in sales of each commodity is estimated using the simulated elasticities. We do not aim for general equilibrium completeness here and estimate the household consumption change due to the transfers by proportionally scaling the base case expenditures.

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 added, which is often referred to as capital compensation.[5] 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 capture 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 be immobile across borders.

The CGE model, an updated version of Adkins and Garbaccio (2007) based on the GTAP 7 database (2004 base year), identifies 8 regions: the United States, Canada, Mexico, China, India, the rest of Annex I, oil-exporting countries, and the rest of the world. The 29 sectors identified (listed in Table 6)

[5] This "other value added" includes the value added of proprietorships, which compensates for both capital and labor of the proprietors.

include 15 manufacturing sectors and 6 energy sectors: coal, oil mining, gas mining, gas distribution, petroleum and coal products, and electricity. The 29 sectors are aggregates of the 52 sectors in the I-O model. The production functions are nested constant elasticity of substitution functions, where capital, energy and labor form a "KLE" aggregate input that is combined with a Leontief nesting of material inputs. Within the KLE bundle there is substitution between capital and energy; and within the energy bundle the electricity input is substitutable with non-electricity inputs. 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). The model calculates 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, one with a carbon tax only and one with a carbon tax combined with the H.R. 2454 subsidies. In the model simulations, these subsidies are applied to 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.[6]

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 revenue recycling and tax interaction effects. Revenues that are recycled back through reductions in other tax rates will reduce pre-existing tax distortions, and thus the overall cost of the program, while revenues 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. That is, in our simulations, any new revenue that is not rebated back as output subsidies is 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 dampen the fall in real consumption expenditures.[7]

IV. Output-Based Rebates under H.R. 2454

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 rebates are industries that have at least a 5 percent energy or greenhouse gas (GHG) intensity and a 15 percent trade intensity,

[6] As noted previously, the border adjustment in H.R. 2454, scheduled to begin in 2020, is not explicitly considered in this analysis.
[7] The alternative assumption of lump sum recycling in the medium- and long-run analyses has a negligible effect on industry results.

where industries are classified according to the six-digit North American Industry Classification System (NAICS).[8] Additionally, other sectors that have an energy, or GHG, intensity greater than 20 percent are also deemed presumptively eligible. Rebates to 43 presumptively eligible industries, based on the historical industry average CO_2 emissions intensity and their current output levels, as determined by the U.S. Environmental Protection Agency (EPA), are incorporated into our calculations. [9,10] Refineries are not eligible for production rebates, although they are freely granted two percent of total allowances without regard to current output levels—i.e., via grandfathering.[11]

H.R. 2454 also allocates 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, widely interpreted to include industrial customers. Because indirect emissions from electricity consumption are an important component of total emissions of the eligible sectors, the LDC provisions were 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.[12]

Table 1 displays our estimates of the dollar value of the EITE allocations and the implied subsidy rates for our 29- and 52-sector aggregations. While the refining industry is not technically eligible for the output-based rebates, we include the value of their grandfathered rebates in the table.[13] The LDC allocations for electric and gas utilities are also translated into output subsidy rates and included in the table. Of the 33 manufacturing industries in the more disaggregated I-O model, 21 are eligible for at least some rebates. The manufacturing sectors receiving the largest subsidies (by value) are in the petroleum refining, ferrous metals, and chemicals industries. We compute the subsidy rate as the ratio of the industry rebate value to the industry output value. These subsidy rates vary considerably among sectors, ranging from 0.001 percent for food manufacturing to 4.38 percent for cement.

The last column of Table 1 gives the qualifying industry share, that is, the portion of industry output presumptively eligible for rebates under H.R. 2454. The last column of Table 1 gives the qualifying industry share, that is, the portion of industry output presumptively eligible for rebates under H.R. 2454. Thus, sectors such as pulp mills and other industries identified at the six-digit NAICS level

[8] 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.

[9] A less generous formula would base allowances on best practices as a benchmark.

[10] 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).

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

[12] 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.

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

qualify for rebates on 100 percent of their output. Sectors such as fertilizer, not comprised entirely of presumptively eligible six-digit NAICS industries, have qualifying shares of less than 100 percent.

Of the 15 manufacturing industries represented in the 29-sector CGE model, nine are eligible for subsidies (including the allocation to refining). In general, the greater level of aggregation means that for most qualifying sectors, both the average subsidy rate and qualifying share of output go down, masking some of the impact of the subsidies. For example, in the more aggregated chemicals, rubber, and plastics sector, the average subsidy rate is 0.241 percent with a qualifying share of output of 30.7 percent. However, in the 52 sector model, petrochemical manufacturing by itself had a subsidy rate of 1.226 percent and a 100 percent qualifying share of output. In the 52-sector model, cement had the highest subsidy rate of all sectors, 4.381 percent. However, in the 29-sector model, it is subsumed within the non-metallic mineral products sector, which has a subsidy rate of only 0.489 percent.

V. Effects of Carbon Pricing with H.R. 2454 Subsidies over Multiple Time Horizons

This section presents the results of our four modeling frameworks designed to represent the very-short-, short-, medium-, and long-run time horizons. To illustrate the effects of an economy-wide carbon pricing policy, we simulate a carbon tax of $15 per ton of CO_2 (2006$) with and without the accompanying subsidies specified in H.R. 2454, i.e. the output-based rebates for EITE industries as well as the free allowance allocations for electricity and gas LDCs and petroleum refining. The most comprehensive results are presented for industrial output, while sector-specific estimates for prices, costs, and profits are presented for some of the modeling horizons. We note that the case with subsidies generates a smaller reduction in CO_2 emissions. Achieving the same emissions reduction with the subsidies would require a slightly higher carbon price.

Effects on Industry Prices: Very-Short-Run Horizon

As noted, the very-short-run horizon was designed to facilitate a hypothetical, worst-case assessment of the maximum damages affected industries might claim. In this scenario, we allow the carbon policy to raise the prices of intermediate inputs; however, we assume that producers cannot raise prices, adjust output levels, change their input mix, or adopt new technologies in response to these higher costs. When calculating the effect on profits, output prices are assumed to remain unchanged. In other words, it is assumed that buyers of an industry's output must pay the carbon tax-inclusive output price (net of any subsidies) but that the producer continues to receive the pre-tax price. There is thus an inherent inconsistency in this very-short-run analysis: firms pay more for their inputs but are unable to recoup the added costs from their customers. The results are therefore valid taken one industry at a time, but they cannot be regarded as applicable simultaneously. An additional value of this exercise is the comparison with the short-run results below where we highlight the importance of output price increases in offsetting reductions in profits.

Table 2 displays the effects of the $15 per ton CO_2 tax on industry prices over the very-short-run horizon for the no-subsidy and subsidy cases.[14] For most manufacturing sectors, industry prices are estimated to increase by less than 2 percent, even without the subsidies. For some sectors, however, price increases are considerably larger: the price of output from the refining-lpg sector is estimated to increase the most (22.5 percent), followed by cement (12.7 percent), and refining-other (10.0 percent). With the subsidies, the estimated price increases are smaller, especially in manufacturing. The manufacturing industries that see the largest reductions in price impacts (in percentage terms) include pulp mills, paper mills, basic organic chemicals, synthetic fibers and filaments, glass containers, iron and steel mills, and alumina refining. For refining, the subsidies reduce the price increase only slightly because the carbon content of these goods is taxed directly. By design, the extractive fossil fuel sectors are also taxed directly and receive no subsidies; their prices rise significantly in proportion to their carbon content, particularly for coal. The two non-manufacturing sectors that are significantly impacted by the subsidy provisions are the electric and gas utilities. For these sectors, the free allocations suppress approximately 75-80 percent of the price increases that would occur otherwise.

Effects on Costs: Very-Short-Run Horizon

Given the changes in industry prices noted above, we next describe the sector-specific effects of the carbon pricing policy on industry costs.[15] The estimated percentage changes in total unit costs without the subsidies are displayed in the first column of Table 3. The next three columns give the contributions to this total from changes in input prices for fuels (direct combustion), purchased electricity, and non-energy intermediate inputs.

The most heavily impacted sector is electricity generation, where costs rise by 9.1 percent, due largely to the significant increase in the price of coal because of the CO_2 tax. Three of the 33 manufacturing sectors – fertilizers, cement, and lime and gypsum – are estimated to experience cost increases exceeding 3 percent. Another seven manufacturing sectors face cost increases between 2 and 3 percent. For the EITE sectors as a whole, the average cost increase is 1.4 percent (shown in the bottom row).[16] The composition of the cost increases vary widely by sector, with some industries most

[14] The I-O framework distinguishes between industries and commodities, where a single commodity may be made by more than one industry. The changes in industry prices reported here are essentially derived by computing the carbon content of the commodity inputs, adjusting for non-combustion uses. The involves computing a modified "Leontief inverse" as explained in Appendix A of Adkins et al. (2010).

[15] For the very-short-run and short-run time horizons, the effects on costs is given by the value of each intermediate input and the change in input prices due to the carbon price. The details are given in equation A21 in Appendix A of Adkins et al. (2010).

[16] While not labeled as an EITE in the interagency report, we include it in our calculations of EITE averages.

affected by the changes in fuel costs (e.g., petrochemical manufacturing), purchased electricity costs (e.g., aluminum), or indirect costs (e.g., fabricated metals). We note that because of the fixed input coefficients assumption, the costs are proportional to the CO_2 tax. A CO_2 price twice as large would double the costs.[17]

The last column in Table 3 shows that total cost impacts are significantly reduced after the subsidies are applied. Only one manufacturing industry, cement, experiences a cost increase greater than 3 percent, and one other industry, lime and gypsum, experiences a cost increase between 2 and 3 percent. The average cost increase for the EITE sectors drops by nearly one half to 0.7 percent (although the EITE average obscures a wide range in reductions across the individual EITE industries). For the non-manufacturing sectors, the introduction of the subsidies also mutes the increases in costs from the CO_2 tax.

Columns 2-4 of Table 3 provide some explanation of the pattern of reductions in the cost impacts with the subsidies. Since primary energy inputs are taxed directly and receive no direct subsidies, the greater the amount of an industry's total cost increase that can be explained by direct fuel purchases, the less effective the subsidies are at reducing the cost increase. Examples include refining, cement, and air transportation, which see their cost increases reduced only about 20 percent. Similarly, electric utilities experience a negligible reduction in their cost increase, since the free allocations they receive do nothing to dampen the increase in their fuel costs. In contrast, aluminum experiences a net cost increase that is more than 75 percent smaller with the subsidies. This is because purchases of electricity are a relatively large share of the original cost increase; thus aluminum benefits from the relatively high subsidy to electric LDCs. At the same time, some of the industries that benefit most are those for which indirect costs are a relatively high share of the pre-subsidy cost impact; examples include machinery, miscellaneous manufacturing, and gas utilities. The increases in their electricity costs are now significantly dampened.

Effects on Output: Very-Short-Run and Short-Run Horizons

As discussed above, in our very-short-run horizon, output levels are fixed and there is an inherent inconsistency between the individual sector results and those for the full set of industries. In contrast, in our short-run horizon the treatment of input and output prices is consistent. In the short-

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[17] Calculations for the very-short- and short-run analyses can be readily scaled up or down to reflect different assumptions about CO_2 prices, since they based on relatively simple linear models. In contrast, modeling of the medium- and long-run horizons explicitly involve nonlinearities that cannot be so readily scaled. However, even for the short-run case, one has to be careful about extrapolating to 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 in the short-run is an issue that must be carefully considered.

run, we assume that producers can raise prices to cover their higher unit costs, with resulting reductions in sales and output as customers switch to alternative goods or imports.[18] Here, any revenues not rebated to industries are recycled to households, preserving the equality between expenditures and receipts.

Table 4 displays the short-run changes in output with and without the subsidies. Without the subsidies, three manufacturing sectors incur output reductions of two percent or more: lime and gypsum (2.3 percent), alumina refining (2.3 percent), and cement (4.8 percent). The relatively large declines in output in these sectors arise from the combined effects of large cost increases and the relatively high demand elasticities estimated for these industries with the CGE model. Consistent with the results shown in Table 3, the subsidies reduce the output losses substantially for many industries. The output loss for cement is reduced by almost one half. For lime and gypsum the output loss is reduced by about one quarter while for alumina refining, which benefits from the substantial allocations to LDCs, the output loss is effectively eliminated. On average, across all EITE industries, the H.R. 2454 subsidies reduce short-run output losses by almost one half.

For the non-manufacturing sectors, the declines in output are generally smaller than for the manufacturing sectors, with a few notable exceptions. As shown in Table 2, coal and other fuel-producing industries saw the biggest increase in prices (for the purchaser, not the producer). Not surprisingly, in Table 4 they now experience the biggest declines in sales, once we account for the effect that these price increases will have on the derived demand for these products. In the case of coal, the output decline is calculated to be more than 30 percent. Electric and gas utilities experience moderate declines in output when the carbon price is introduced but see those losses cut by 80 percent when the subsidies are included. The service sectors, which gain slightly in the no-subsidy case, gain less with the subsidies, as the amount recycled back to households is halved, limiting the amount of expenditure switching to less carbon intensive commodities.

Effects on Profits: Very-Short-Run and Short-Run Horizons

Table 5 displays the effects of the carbon pricing policy on profits in the very-short-run and short-run horizons, both with and without the subsidies. The effects are particularly pronounced in our very-short-run scenario, since by assumption firms have no recourse but to absorb the full impact of these cost increases as reductions in profits.[19] Looking first at the bottom row, which gives the weighted average results for the EITEs plus petroleum refining sectors, we see that the imposition of a

[18] 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 in Adkins et al. (2010).
[19] We define profits as the gross return to capital – i.e. sales revenue plus any applicable rebates, minus purchases of intermediate inputs and labor costs. See Appendix A in Adkins et al. (2010).

$15 per ton carbon price reduces profits by an average of almost 12 percent. In the short-run, when we allow firms to increase their output prices and introduce downward sloping demand curves for their products, the average reduction in profits for this group falls 96 percent to less than half a percent. The H.R. 2454 subsidies reduce the profit reduction by an additional 50 percent (comparing the second and fourth columns in Table 5).

A similar story applies to most individual industries. For example, without the subsidies, fertilizers, artificial and synthetic fibers and filaments, and other basic organic chemicals experience declines in profits of 78.7, 62.7, and 54.5 percent, respectively, in the very-short-run when the output price is fixed vs. 1.5, 0.5, and 1.1 percent declines when they are free to raise output prices. With the H.R. 2454 subsidies, the profit declines are further reduced by another 65-85 percent.

Among the non-manufacturing sectors, in the very-short-run, several industries experience profit declines over 5 percent, with significantly higher losses for air transportation and electric utilities. However, in our short-run case, once output prices are allowed to rise, only electric and gas utilities and the fossil fuel producing sectors experience impacts on profits greater than one percent. Once the subsidies are applied, this is limited to only the fossil fuel producing sectors, given the relatively generous allocation to LDCs.

Comparing Effects on Output over the Short-, Medium-, and Long-Run Horizons

We next compare the short-run effects on output to those over our medium- and long-run horizons. As noted in Section III, the global CGE model used to consider the latter two horizons identifies 29 industries. In order to compare the estimates across the three horizons, we first aggregate the results for the 52 industries used in the short-run analysis into the corresponding 29 industry categories using output values as weights. We focus on the case where a $15 per ton CO_2 (2006$) price is adopted in all Annex I nations (as opposed to unilateral U.S. action).

Table 6 displays the effects on output of the carbon pricing policy across the three modeling horizons both with and without the H.R. 2454 subsidies.[20] Figure 1 shows the effects in the three horizons for the manufacturing sectors in the no-subsidy case. 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 between sectors and/or substitute it

[20] Not surprisingly, the impact of carbon pricing policies on output levels is quite sensitive to the breadth of the industrial categories considered: the more narrowly the categories are defined, the greater the variation in impacts. For example, the short-run output decline is 64 percent larger for inorganic chemicals (column one of Table 4) than it is for chemicals, rubber, and plastics (column one of Table 6). Although the availability of consistent information dictated our present choice of aggregation, in earlier work, Morgenstern et al. (2004) found that sub-industry impacts estimated at a four-digit SIC (Standard Industrial Classification) level can be an order of magnitude larger those estimated at a two-digit level.

for energy or labor. Furthermore, in the general equilibrium framework, both producers and consumers are changing their behavior in response to a price on carbon, and these may have opposing effects on output over time. On the one hand, producers are substituting inputs to reduce the cost impact and hence prices; i.e. shifting the supply curve back out. Over time, these lower prices should help raise sales and output. On the other hand, customers are making substitutions to avoid higher prices for carbon intensive products, reducing their demands (shifting the demand curve back), and thereby reducing sales and output of these products.

Looking across the first three columns of Table 6, we see these competing effects at work in the no-subsidy case. Results for the manufacturing sectors are also presented in Figure 1. While most of the manufacturing sectors see reductions in output with the CO_2 tax in the short-run, the magnitude of the decline in the medium-run may be greater or smaller in comparison. However, for the EITE sectors as a group, the average output decline is twice as great in the medium-run (bottom row of Table 6). For the non-manufacturing sectors, the differences between short- and medium-runs is mixed. For the coal and gas mining sectors, the decline in output is much smaller in the medium-run. For the transportation sector the results are the opposite, with a much greater decline in the medium-run. A number of the remaining non-manufacturing sectors see small increases in output as households substitute into less carbon intensive goods.

In contrast to the medium-run, the long-run allows for substitution of capital for other inputs. For the most part, the differences between the medium- and long-run changes in output are smaller than when comparing the short- and medium-runs. For the manufacturing sectors, the reduction in output in the petroleum and coal products sector is significantly greater in the long-run as the economy continues to adjust away from carbon intensive goods. For the nonferrous and ferrous metals sectors the effect is the opposite, with reductions in output smaller in the long-run. For the EITE sectors as a group, the average decline increases from 0.9 to 1.0 percent. Coal, gas, and oil mining all see greater declines in output in the long-run.

For those sectors receiving them, the H.R. 2454 subsidies can have significant effects on output across all of the horizons. As show in Table 6, the average decline in output for the EITEs drops from 0.5 percent without the subsidies to 0.2 percent with the subsidies in the short-run, from 0.9 to 0.3 percent in the medium-run, and from 1.0 to 0.3 percent in the long-run. Figure 2 shows the long-run effect of the subsidies on all of the sectors that receive allocations. They are particularly significant for the electric utilities sector, which goes from a significant decline in output to a small increase. Both the nonferrous and ferrous metals sectors also see significant reversals with the subsidies. Of the sectors that do not receive subsidies, the coal mining sector is the biggest beneficiary.

Beyond these results for carbon pricing across all Annex I countries, it is also instructive to consider the impacts of unilateral action by the U.S. Clearly, the output losses under unilateral action would be larger, since roughly half of U.S. trade in energy intensive goods is with other Annex I nations. To examine this issue, we simulate the models covering all three timeframes under the assumption that only the U.S. imposes a $15 per ton carbon price. Without the H.R. 2454 subsidies, the average output losses for all EITE industries plus petroleum products are 1.4, 0.4, and 0.4 times larger than the case of multilateral action, for the short-, medium-, and long-run horizons, respectively (the details are given in Adkins et al. 2010). With the H.R. 2454 subsidies, the output losses in the unilateral scenario are 0.8, 1.4 and 1.1 times larger. Thus, even though we are dealing with relatively small impacts, especially once the subsidies are applied, we see the importance of multilateral action in attenuating losses.

VI. Trade and Leakage

A sub-global carbon pricing policy will not only affect firms' costs, output, and short-run profits, but will also impact international trade, relocating economic activity from high regulatory cost to low regulatory cost nations. These trade impacts, also known as competitiveness effects, can lead to emissions leakage.[21] Beyond the direct trade impacts, ensuing changes in world fuel prices can further alter relative costs across countries, changing the carbon-intensity of production and leading to additional leakage. Here we estimate the trade-related impacts of our Annex I-wide carbon pricing policy and the implications for emissions leakage on a sectoral basis. We examine leakage attributable to changes in trade volumes as well as leakage related to differences in the carbon-intensity of production in different regions. We also explore the impacts of the policies on aggregate leakage from the U.S. and other Annex I countries with carbon policies, accounting for leakage at both the industry and household levels.

Trade Impacts

In previous sections, we estimated the changes in domestic output induced by the imposition of a domestic carbon pricing regime with and without the subsidies 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 for through changes in trade. Specifically, the change in domestic production of commodity *i* (Q_i) can be decomposed into the changes in consumption plus exports minus imports[22]:

(1) $$\Delta Q_i = \Delta C_i + \Delta EX_i - \Delta MX_i$$

[21] Note that these trade impacts are consistent with the well-known pollution-haven hypothesis (Jaffee et al., 1995).

[22] Ignoring changes in inventories, which are not modeled here.

The trade impact of the policies can then be defined as the share of the change in output due to the changes in exports and imports[23]:

(2) $$\text{Trade Impact} = \frac{\Delta EX_i - \Delta MX_i}{\Delta Q_i}$$

Table 7 presents the results of the decompositions of the changes in output for the medium-run, both with and without the subsidies. Table 8 presents the results for the long-run. Figure 3 shows the decompositions for the manufacturing sectors in the medium-run without the subsidies. We can see how the decompositions operate by taking the chemicals, rubber, and plastics sector as an example. In the medium-run, following the imposition of the carbon tax without subsidies, sectoral output falls by 1.55 percent (Table 7). Domestic consumption, however, falls by less, as exports fall and imports rise to make up the difference. The decrease in consumption contributes 0.55 percentage points to the change in output, the decrease in exports 0.79 percentage points, and the increase in imports 0.21 percentage points. Filling in equation (1) we can confirm that: - 1.55 = (- 0.55) + (- 0.79) - (0.21). Taking the component due to changes in trade alone, the trade impact for the chemicals, rubber, and plastics sector is 64 percent of the total decline in output, i.e., [(- 0.79) – (0.21)]/(- 1.55).

As can be seen in Figure 3, in addition to the chemicals, rubber, and plastics sector, trade impacts explain a significant portion of the fall in output for the nonferrous metals, non-metallic mineral products, and ferrous metals sectors, accounting for 61, 56, and 53 percent, respectively, of the fall in their output in the medium-run. For the petroleum refining sector, by contrast, the decline in domestic consumption comprises the bulk of the output decline, with only 13 percent of the total coming from changes in trade. For the EITE sectors as a whole, in the medium-run, the trade or competitiveness accounts for 46 percent of the fall in output. As can be seen in Figure 3, the trade effects can also work in the opposite direction. For example, in the machinery sector, a decrease in domestic consumption is largely offset by the combined effects of an increase in exports and a decrease in imports.

Without the subsidies, the composition of the changes in sectoral output in the long-run is similar to those in the medium-run. However, in the long-run, the ability of capital to migrate between sectors reduces international cost disparities and attenuates some of the trade impacts. Thus, the trade impacts for the EITEs fall from 46 percent in the medium-run to 33 percent in the long-run.[24] As we saw

[23] Aldy and Pizer (2011) define the “competitiveness effect” as the percentage change in net imports.

[24] Aldy and Pizer (2011), using an econometric approach, estimate short-run (one year) competitiveness effects for more than 400 U.S. manufacturing industries. Although their methodology is not directly comparable with ours, it is worth pointing out that where sectoral dissagreagtion is roughly similar, our change in net imports is comparable with theirs. However, the estimated changes in their output measure is in all cases significantly larger than in our simulation results. The net effect is that our trade impact measure is much larger than their comparable measure.

in the previous section, for sectors that receive them, the subsidies significantly reduce the declines in output that accompany imposition of the carbon tax (or in several cases actually increase sectoral output). With the subsidies spurring increases in exports and decreases in imports for several sectors, the net effect is a decrease in trade impacts for the EITE sectors. In the long-run, with the subsidies in place, the impact for the EITE sectors falls to 3 percent. This is a much stronger effect than in the medium-run, where the subsidies reduce the trade impacts for the EITE sectors from 46 to 37 percent.

Emissions Leakage at the Industry Level

We now move beyond our examination of the trade impacts on U.S. industrial output to estimate trade-related emissions leakage at the industry level. The $15 per ton CO_2 price in Annex I countries can be anticipated to cause emissions to leak to non-policy countries outside Annex I, due in part to changes in trade flows. Here we decompose sectoral leakage from the U.S. to non-Annex I countries into components that arise from changes in the volume of trade with the U.S. and changes in the carbon-intensity of that trade. Table 9 presents calculations for the long-run case without subsidies for the manufacturing sectors.

The first column of Table 9 shows the estimated change in U.S. CO_2 emissions by sector, which includes both direct emissions and indirect emissions from the use of electricity. Columns 2-4 decompose the change in non-Annex I emissions, i.e. leakage, by sector. The second and third columns show the changes in non-Annex I emissions related to changes in exports to and imports from the U.S. The fourth column shows the change in Annex I emissions related to the change in the carbon intensity differential of production between the U.S. and its non-Annex I trading partners. The final column gives the estimated sectoral trade-related leakage rates. Figure 4 shows the sectoral leakage rates and their trade- (i.e., net export) and intensity-related components, computed from Table 9.

The highest estimated trade-related leakage rate is 27.1 percent for the petroleum refining sector. Almost 40 percent of the increase in emissions there is due to the change in the emissions intensity differential between the U.S. and its non-Annex I trading partners. Four other sectors, all EITEs, have trade-related leakage rates greater than 5 percent. For the EITEs as a group, the estimated leakage rate is 8.5 percent. Seven of the fifteen manufacturing sectors actually have negative trade-related leakage rates. If we were to exclude the change in the carbon intensity differential between the policy and non-policy countries, the trade-related leakage rate for the EITEs would fall to 3.9 percent.

For the manufacturing sectors, Table 10 compares the emissions changes and trade-related leakage rates from Table 9 with estimates that include the subsidies. As discussed previously, with the

For example, their competitiveness effect for their chemicals sector is 1.3 percent. For the medium-run, our comparable measure is 1.0 percent. However, Aldy and Pizer estimate a 3.4 percent fall in output, while our simulation result is a fall of 1.6 percent.

subsidies and the same $15/ton tax, the total emissions reduction in the U.S. will be lower than in the case with the tax alone. This is evident at the sectoral level when comparing columns 2 and 4 in Table 10. Both the numerator and denominator for the leakage estimates may change when the subsidies are applied. In this case, the leakage rate for the petroleum refining sector goes up, while the estimates for the other four sectors which previously had leakage rates over 5 percent all go down. At the same time, leakage rates for a number of sectors that do not receive subsidies go up.

Overall, the trade-related leakage rate for the EITEs goes down to 5.3 percent. Although we saw earlier that the subsidies were generally effective at reducing or even reversing sectoral output losses (Table 6), they reduce less than 40% of trade-related leakage in our estimates. This contrasts with the interagency report discussed earlier, which ignores how the carbon pricing policy will alter the differential in the carbon intensity of trade between the U.S. and non-policy countries. In that analysis, allocations to LDCs and trade-vulnerable industries virtually eliminated leakage in each of the five EITE sectors examined.

Aggregate Leakage

We now look at changes in emissions in all countries and regions in our CGE model and calculate the aggregate leakage rates. We decompose the changes in emissions into components for industry and households. We further decompose industry changes into components for output and emissions intensity. Table 11 presents the decompositions for countries adopting carbon pricing policies and for the non-policy countries. Estimates are presented for the cases both with and without subsidies in the U.S. We focus here on the long-run (i.e., mobile capital) case.

The first column of Table 11 displays the base year level of emissions. In 2004, the United States emitted 6,070 million tons of CO_2, 23 percent of global emissions. In the no-subsidy case, U.S. emissions fall by 518 million tons (8.6 percent). Emissions in the other Annex I countries implementing the same carbon price (i.e., Canada and Rest of Annex I) fall by 648 million tons, resulting in total Annex I reductions of 1,167 million tons. Emissions in the non-policy (i.e., non-Annex I) countries rise by 103 million tons for an aggregate leakage rate across Annex I nations of 8.8 percent.

When the subsidies are introduced, U.S. output falls by somewhat less than in the no-subsidy case, and so do corresponding emissions, by 441 million tons. Total Annex I reductions also fall somewhat less, by 1,064 million tons. At the same time, the smaller reduction in U.S. output leads to a smaller drop in international fuel prices compared to the no-subsidy case, and non-Annex I emissions increase less, by 92.4 million tons. The result is a slightly smaller leakage rate of 8.7 percent. Mathematically, both the numerator and denominator of the leakage rate are reduced, with the denominator decreasing relatively less.

We next look more deeply into the sources of changes in country emissions. For the U.S. and the rest of the world we decompose emissions changes into those from industry and households. For industry we decompose the changes further, into those resulting directly from changes in sectoral output levels and those resulting from changes in emissions intensity:

$$(3) \qquad \Lambda_r = \sum_i \theta_{ir}^{P} \cdot \left(Q_{ir}^{P} - Q_{ir}^{0}\right) + \sum_i \left(\theta_{ir}^{P} - \theta_{ir}^{0}\right) \cdot Q_{ir}^{0} \quad ,$$

where Λ_r is the change in country or region emissions, Q_{ir} is sector *i* output in country *r*, and θ_{ir} is the emissions intensity of output for sector *I* in country *r*. The superscripts *0* and *P* denote the variables for the base and policy cases. Changes in θ_{ir} are driven by substitution among fuel inputs, resulting directly from the carbon policies and indirectly from changes in world fuel prices.

The bottom two panels of Table 11 show the results of the decompositions of the emissions changes in the U.S. and elsewhere. With the carbon tax imposed in the U.S. and other Annex I countries (without any subsidies in the U.S.), the change in emissions directly attributed to changes in household consumption is 13.3 percent for the U.S. and 19.0 percent outside of the U.S. The change in input mix is the largest contributor to the change in emissions in both the U.S. and abroad, accounting for 62.4 percent and 74.7 percent of the totals, respectively. Changes in industrial output levels (weighted by the sectoral emissions coefficients), accounts for the rest of the changes, at 24.4 percent in the U.S. and 6.3 percent abroad. With the subsidies in place in the U.S., sectoral output changes less than in the no-subsidy case and the change in emissions attributable to output changes falls to 4.5 percent, with that from input substitution rising to 81.5 percent.

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 in the short-run.

Industry leakage is also sensitive to the choice of 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 in our global model that are available in the more disaggregated I-O model, import responses and leakage likely would be greater for some sectors and smaller in others.

VII. Conclusions

Inevitably, any broad-based carbon pricing policy will have disproportionate impacts on certain industries. Some of the key challenges to developing a CO_2 pricing policy addressed in this paper include: 1) identifying which industries face the greatest impacts and evaluating how these impacts may change over time as producers and consumers adjust; 2) estimating the associated trade (i.e., competitiveness) impacts and emissions leakage; and 3) assessing to what extent the various impacts can be mitigated by offsetting policies, such as the output-based rebates and free allowance allocations of the type contained in H.R. 2454.

In this paper we introduce a multi-horizon methodology that tries to address the dynamic adjustment issue: (1) the very-short-run examines the maximum losses that industries might try to claim, assuming that sellers are not able to pass through their cost increases; (2) the short-run allows for cost pass-through but assumes no input substitution; (3) the medium-run allows for cost pass-through and incorporates input substitution except for capital; (4) the long-run allows for cost pass-through and substitution among all inputs. In order to identify the hardest hit industries we developed a U.S. input-output model with 52 sectors, some at a highly disaggregated level, for analyzing the first two time horizons. For the third and fourth horizons we use a 29 sector global CGE model to assess the key impacts, including trade effects. The effectiveness of the offsetting policies contained in H.R. 2454 – translated into their subsidy equivalents – is considered in all four horizons.

With this methodology we are able to derive some results generally not available in other studies. First, we identify the industries most affected by a carbon price at a disaggregated level. Second, we show how output and profit losses may change substantially over time when output prices can adjust and producers can substitute inputs. These dynamic results should allow a more nuanced and critical discussion of industry claims of damages; losses may increase or decrease over time and may require a more complex compensation strategy. Third, we show that the subsidies substantially reduce losses for the industries directly affected, and for other industries through the inter-industry framework. We also show how these subsidies affect trade flows and examine their effectiveness at addressing competitiveness and leakage impacts of subglobal carbon pricing. Fourth, we examine emissions leakage on both aggregate and industry levels and decompose them into various components.

Examination of the results of our simulations of a $15/ton CO_2 price across Annex I countries, combined with the H.R. 2454 subsidies in the U.S., yields a number of observations:

- Focusing on the short-run, when certain simplifying assumptions allow for a more disaggregated analysis, we observe that the most pronounced impacts are concentrated in particular sub-segments of the EITE industries. Without the subsidies, the biggest short-run output losses in manufacturing occur in the cement, aluminum, and lime and gypsum sectors. With the subsidies, on average, short-run losses for the EITE industries are cut in half.
- A reduction in output losses does not always occur as we move through successively longer time frames in the analysis, suggesting that the passage of time by itself may not be sufficient to attenuate the impacts. However, we do find that use of the H.R. 2454 subsidies can significantly offset output losses in each of the four time frames considered. Within manufacturing, with the exception of petroleum and coal products, the subsidies keep output losses under 0.6 percent in the short-run and under 0.5 percent in the medium- and long-runs. In the non-manufacturing sector, the output losses of the electric and gas utilities sectors shrink even more dramatically as a result of the allocations to local distribution companies.
- In the near-term, EITE industries' ability to raise prices in the face of the domestic carbon pricing policy is key to their sustained profitability. The average loss of profits in the EITE industries shrinks by more than 25-fold when output prices are allowed to rise (the short-run) – even without the subsidies – compared to the case where output prices are fixed (the very-short-run). Indeed, on average we find that the ability of firms to raise prices is considerably more important in stemming profit losses for EITEs than the application of the subsidies alone. When price increases are combined with the subsidies, profit losses in the EITE industries fall by another half to an average of 0.23 percent.
- We find that without subsidies, the increase in net imports for individual EITE sectors is generally less than one percent, and shrinks when moving from the medium- to long-run. Applying the subsidies either reduces the increase in net imports or reverses its sign. On average, without the subsidies, trade or "competitiveness" impacts explain 46 percent of the decline in EITE output in the medium-run and 33 percent in the long-run. With the subsides, trade impacts for the EITEs fall to 37 percent in the medium-run and 3 percent in the long-run; for some of the EITEs, the trade impacts actually increase sectoral output.
- We estimate that about half of trade-related leakage from the U.S. to non-policy countries is due directly to changes in the volume of trade, and the other half to higher emissions intensities in non-Annex I trading partners induced by lower world fuel prices. While the H.R. 2454 subsidies are

generally effective in reducing output losses for targeted sectors, they are less effective in reducing leakage.

Overall, while some of our estimates are sensitive to the inevitable modeling assumptions, we believe that our main conclusions regarding the most affected industries and the effects of the rebates are robust. The dynamic effects are subject to greater uncertainty and highlight the importance of more research into adjustment costs and the degree of input substitution.

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Figure 1: Short-, Medium-, and Long-Run Effects on Output of a \$15/ton CO_2 Tax (% change)

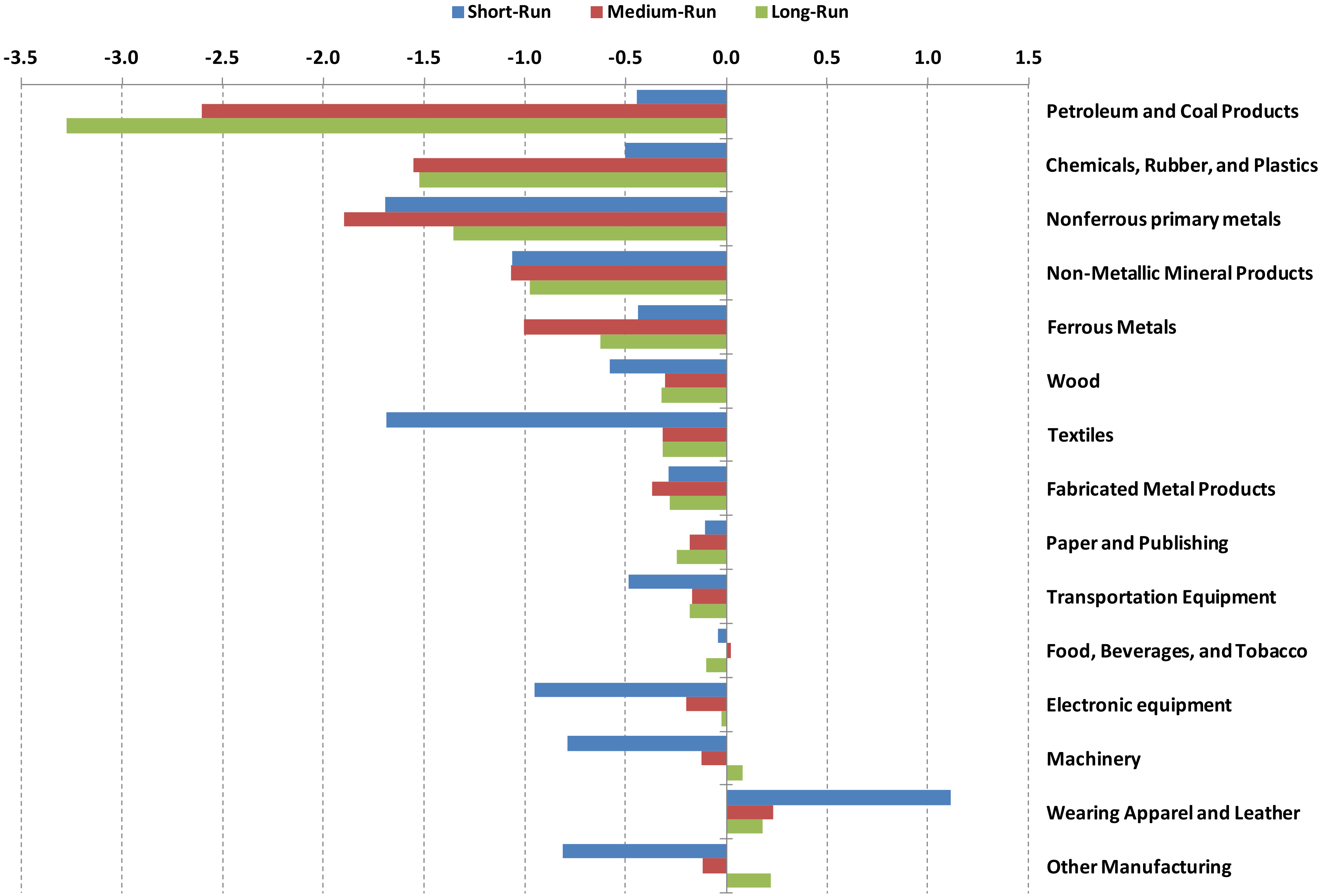

Figure 2: Long-Run Effect on Output of a $15/ton CO_2 Tax with and without Subsidies (% change)

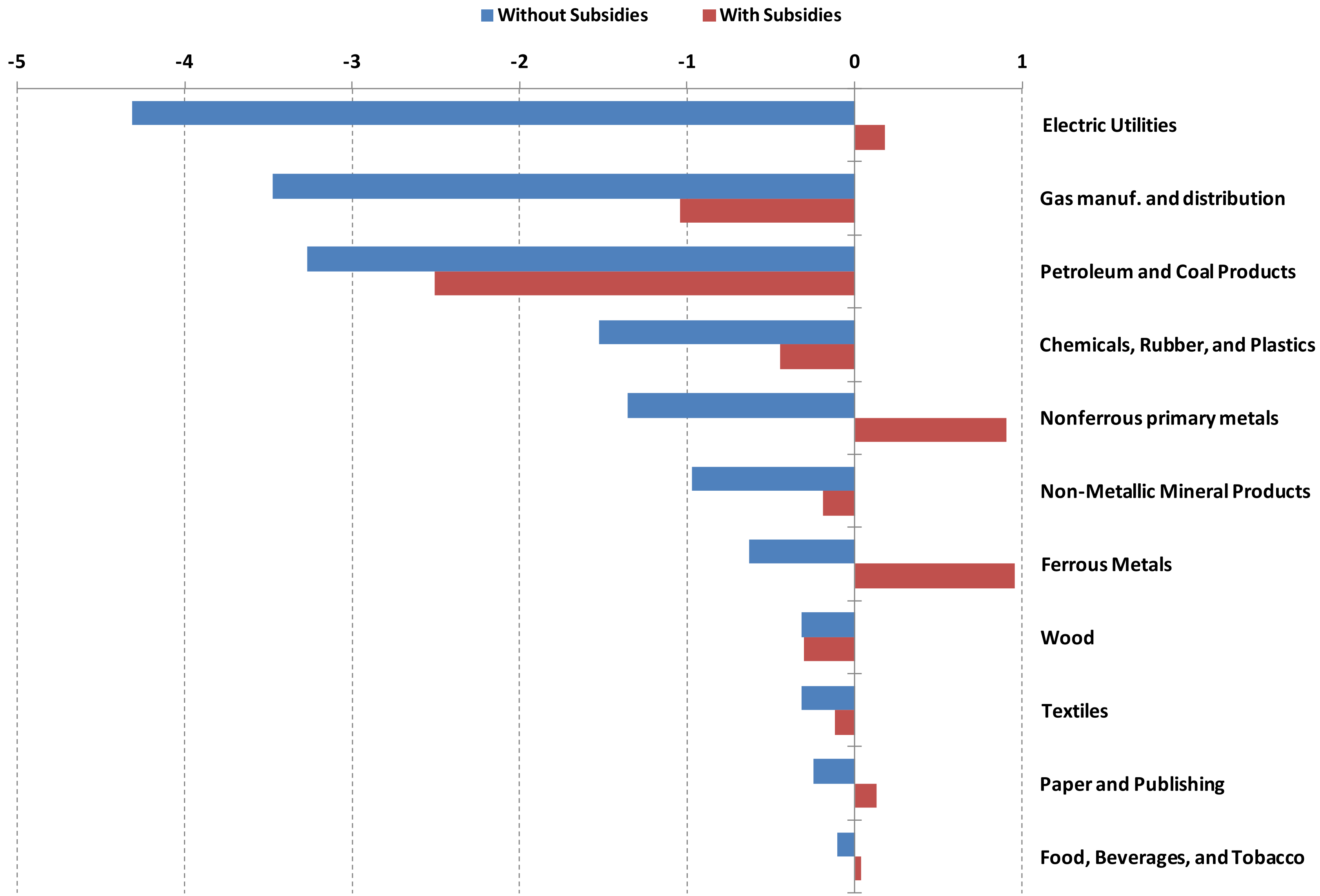

Figure 3: Decomposition of Medium-Run Effects on Output of a \$15/ton CO_2 Tax (% change)

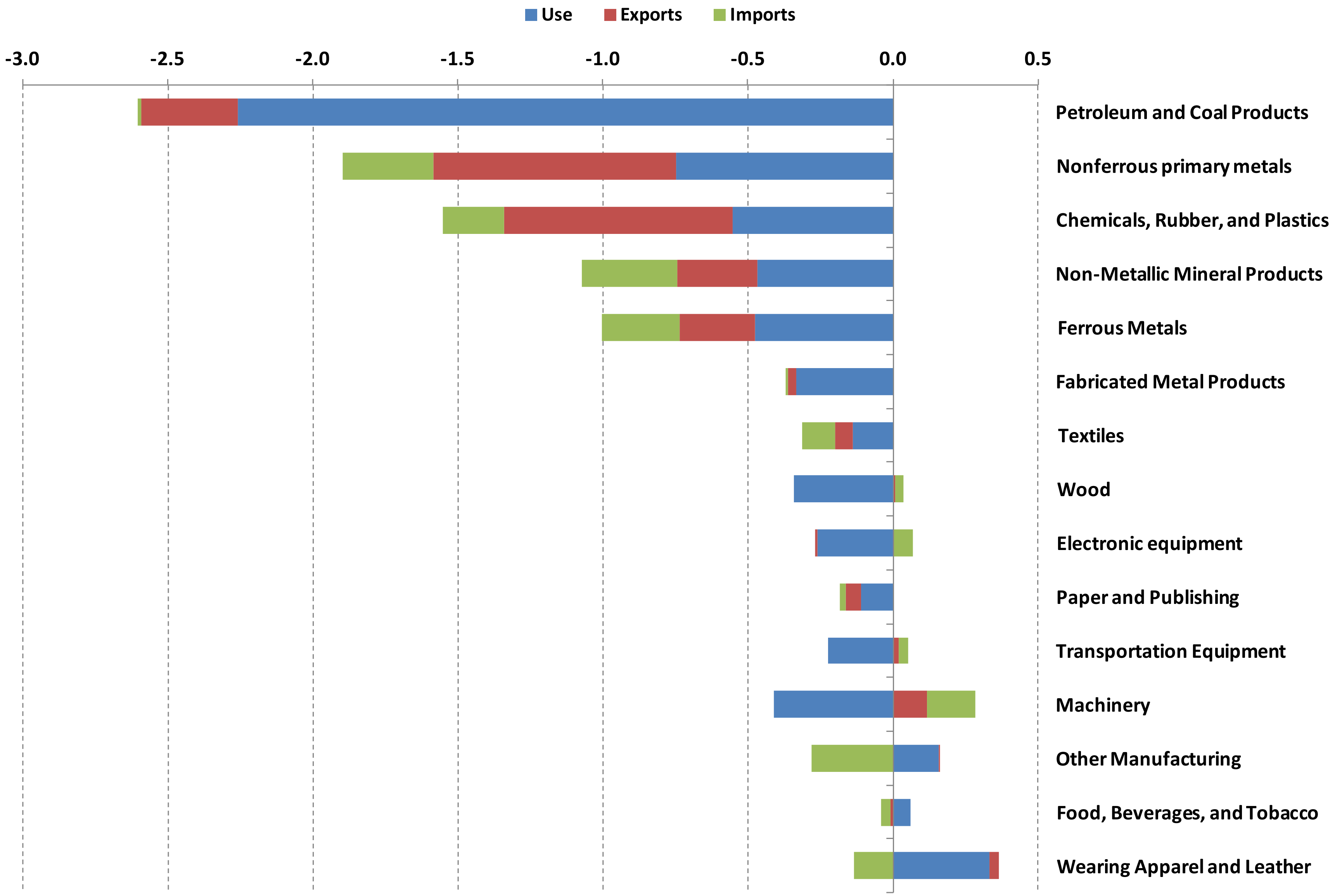

Figure 4: Long-Run Emission Leakage Rates for Manucturing Sectors with $15/ton CO_2 Tax (% change)

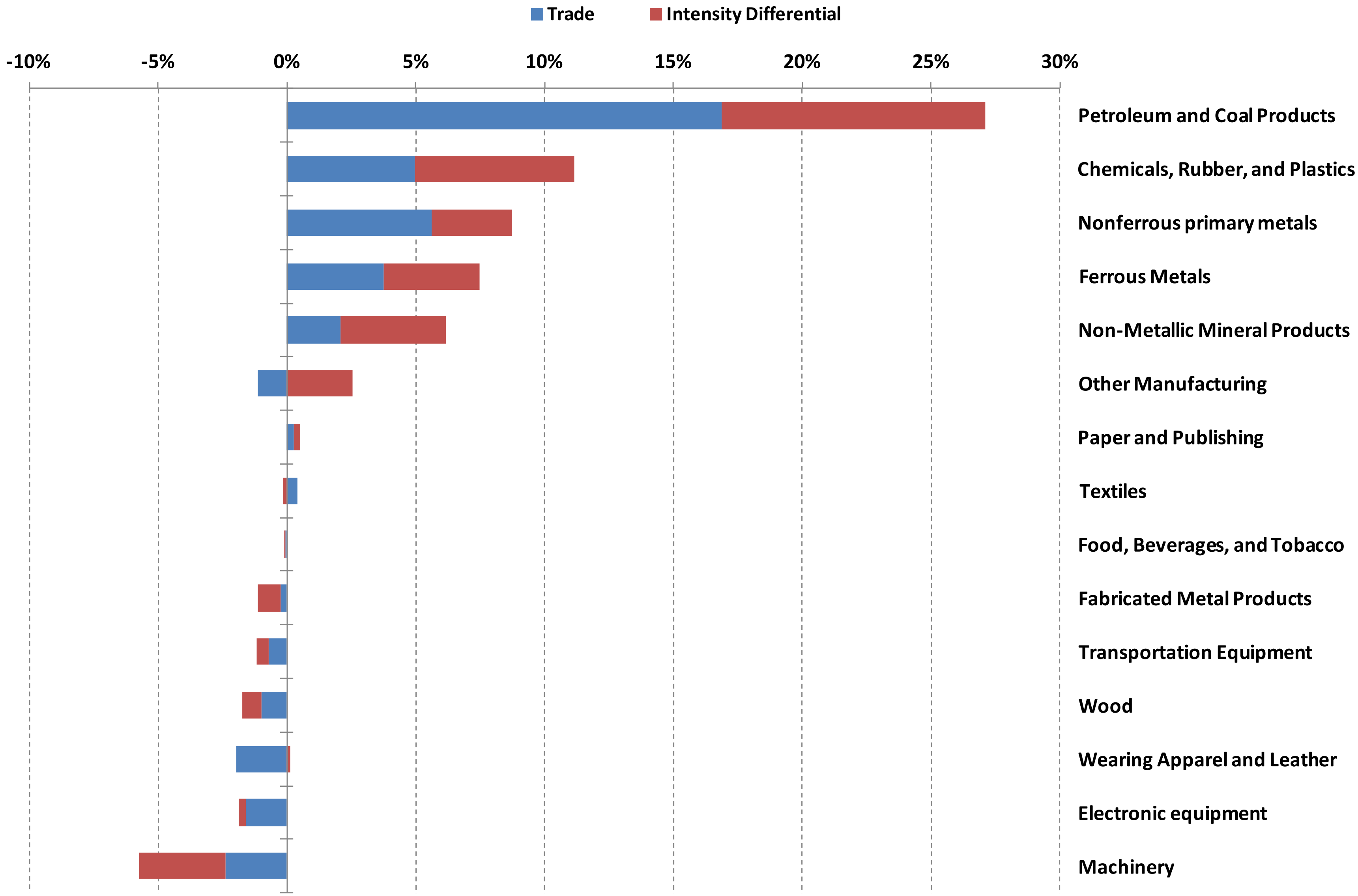

Table 1. H.R. 2454 Allowance Allocations (subsidy equivalents, based on 2006 Data)

Sector	Value of Subsidy (million $)	Subsidy Rate (% of Output)	Qualifying Share of Output (%)
Food, Beverages, and Tobacco*	8.3	0.001%	1.4%
Textiles*	3.1	0.005%	1.6%
Wood and Furniture*	15.9	0.010%	4.1%
Paper and Publishing*	405.2	0.157%	21.5%
*Pulp mills**	*32.0*	*0.771%*	*100.0%*
*Paper mills**	*373.2*	*0.727%*	*100.0%*
Paperboard mills	*0.0*	-	*0.0%*
Other paper	*0.0*	-	*0.0%*
Petroleum and Coal Products**	2,019.9	0.422%	100.0%
*Refining-lpg***	*114.1*	*0.422%*	*100.0%*
*Refining-other***	*1,905.8*	*0.422%*	*100.0%*
Chemicals, Rubber, and Plastics*	1,765.3	0.241%	30.7%
*Petrochemical manufacturing**	*644.8*	*1.226%*	*100.0%*
*Basic Inorganic chemical manufacturing**	*150.0*	*0.584%*	*100.0%*
*Other basic organic chemical manufacturing**	*763.2*	*1.022%*	*100.0%*
Plastics and material resins	*0.0*	-	*0.0%*
*Artificial and synthetic fibers and filaments**	*67.7*	*0.796%*	*100.0%*
*Fertilizers**	*62.8*	*0.568%*	*32.4%*
*Other chemical and plastics**	*76.7*	*0.016%*	*12.4%*
Non-Metallic Mineral Products*	584.8	0.489%	33.2%
*Glass containers**	*29.8*	*0.678%*	*100.0%*
*Cement**	*451.5*	*4.381%*	*100.0%*
*Lime and gypsum**	*35.4*	*0.396%*	*18.5%*
*Mineral wool**	*26.5*	*0.412%*	*100.0%*
*Other nonmetallic minerals**	*41.6*	*0.046%*	*18.9%*
Ferrous Metals*	905.4	0.876%	80.6%
*Iron and steel mills and ferroalloy**	*905.4*	*1.087%*	*100.0%*
Ferrous metal foundries	*0.0*	-	*0.0%*
Nonferrous primary metals*	151.3	0.185%	39.5%
*Alumina refining, etc.**	*135.5*	*0.591%*	*100.0%*
Non-ferrous metal foundries	*0.0*	-	*0.0%*
*Other primary metals**	*15.8*	*0.034%*	*20.3%*
Electric Utilities**	26,933.0	7.234%	-
Gas Manufacturing and Distribution**	8,079.8	7.005%	-

Note: Four-digit NAICS subsectors in 52-sector IO model are indented and italicized. EITE sectors are denoted by *. Other sectors which receive subsidies are denoted by **.

Source: EPA (2009b) and authors' calculations.

Table 2. Very-Short-Run Effect of $15/ton CO_2 Tax on Industry Output Prices (% change)

	Sector	Without H.R. 2454 Subsidies	With H.R. 2454 Subsidies
Manufacturing Industries	Food	0.98%	0.40%
	Textiles	1.56%	0.44%
	Apparel	0.52%	0.16%
	Wood & Furniture	1.00%	0.42%
	Pulp Mills	1.89%	0.21%
	Paper Mills	1.96%	0.13%
	Paperboard Mills	2.51%	1.12%
	Other Paper	1.06%	0.28%
	Refining-LPG	22.53%	21.72%
	Refining-Other	9.98%	9.19%
	Petrochemicals	2.70%	0.52%
	Basic Inorganic Chemicals	1.78%	0.13%
	Other Basic Organic Chemicals	2.33%	0.40%
	Plastics and Material Resins	1.77%	0.76%
	Artificial & Synthetic Fibers, Filaments	2.27%	0.16%
	Fertilizer	3.05%	0.85%
	Other Chemicals & Plastics	1.05%	0.31%
	Glass Containers	2.23%	0.00%
	Cement	12.65%	6.99%
	Lime and Gypsum	6.24%	4.68%
	Mineral Wool	1.72%	0.18%
	Other Nonmetallic Minerals	1.93%	0.87%
	Iron and Steel Mills and Ferroalloys	2.31%	0.19%
	Alumina Refining, Primary & Secondary Aluminum	2.50%	0.02%
	Ferrous Metal Foundries	1.59%	0.56%
	Non-Ferrous Metal Foundries	1.34%	0.28%
	Other Primary Metals	1.65%	0.37%
	Fabricated Metals	1.12%	0.20%
	Machinery	0.83%	0.18%
	Computer & Electrical Equipment	0.55%	0.15%
	Motor Vehicles	0.98%	0.25%
	Other Transportation Equipment	0.65%	0.16%
	Miscellaneous Manufacturing	0.64%	0.18%
Non-Manufacturing Industries	Agriculture	1.13%	0.60%
	Forestry, Fishing, etc	0.42%	0.21%
	Oil Mining	16.32%	16.14%
	Gas Mining	9.07%	8.90%
	Coal Mining	131.96%	131.61%
	Other Mining Activities	1.19%	0.75%
	Electric Utilities	9.11%	1.73%
	Gas Utilities	9.45%	2.23%
	Construction	0.72%	0.35%
	Trade	0.34%	0.14%
	Air Transportation	2.28%	1.74%
	Truck Transportation	1.31%	0.90%
	Other Transportation	0.81%	0.57%
	Information	0.36%	0.12%
	Finance and Insurance	0.17%	0.06%
	Real Estate and Rental	0.38%	0.11%
	Business Services	0.30%	0.13%
	Other Services	0.40%	0.14%
	Government	0.73%	0.41%

Source: Authors' calculations.

Table 3. Very-Short-Run Effect of $15/ton CO_2 Tax on Costs (% change)

		Without Subsidies				With Subsidies
			Of which change in cost of:			
	Sector	Change in Total Cost	Fuel	Purchased Electricity	Indirect Cost	Change in Total Cost
Manufacturing Industries	Food	0.98%	0.20%	0.11%	0.67%	0.40%
	Textiles	1.56%	0.32%	0.35%	0.89%	0.44%
	Apparel	0.52%	0.03%	0.06%	0.43%	0.16%
	Wood & Furniture	1.00%	0.30%	0.18%	0.52%	0.42%
	Pulp Mills	1.89%	1.01%	0.33%	0.54%	0.99%
	Paper Mills	1.96%	0.87%	0.49%	0.59%	0.86%
	Paperboard Mills	2.51%	1.28%	0.75%	0.48%	1.12%
	Other Paper	1.06%	0.11%	0.13%	0.82%	0.28%
	Refining-LPG	1.40%	1.19%	0.07%	0.14%	1.10%
	Refining-Other	1.35%	1.14%	0.07%	0.14%	1.06%
	Petrochemicals	2.69%	1.87%	0.07%	0.76%	1.74%
	Basic Inorganic Chemicals	1.77%	0.43%	0.74%	0.60%	0.71%
	Other Basic Organic Chemicals	2.27%	1.37%	0.23%	0.68%	1.41%
	Plastics and Material Resins	1.72%	0.74%	0.20%	0.78%	0.74%
	Artificial & Synthetic Fibers, Filaments	2.24%	0.67%	0.49%	1.09%	0.95%
	Fertilizer	3.05%	2.22%	0.27%	0.55%	1.42%
	Other Chemicals & Plastics	1.03%	0.21%	0.21%	0.62%	0.33%
	Glass Containers	2.23%	1.17%	0.68%	0.38%	0.68%
	Cement	5.85%	4.61%	0.92%	0.32%	4.58%
	Lime and Gypsum	3.47%	2.65%	0.28%	0.54%	2.31%
	Mineral Wool	1.72%	0.63%	0.50%	0.60%	0.59%
	Other Nonmetallic Minerals	1.93%	0.40%	0.18%	1.35%	0.91%
	Iron and Steel Mills and Ferroalloys	2.31%	1.25%	0.48%	0.57%	1.30%
	Alumina Refining, Primary & Secondary Aluminum	2.46%	0.53%	1.53%	0.41%	0.59%
	Ferrous Metal Foundries	1.59%	0.49%	0.49%	0.61%	0.56%
	Non-Ferrous Metal Foundries	1.34%	0.34%	0.29%	0.71%	0.28%
	Other Primary Metals	1.61%	0.21%	0.32%	1.08%	0.38%
	Fabricated Metals	1.12%	0.09%	0.12%	0.91%	0.20%
	Machinery	0.83%	0.03%	0.09%	0.71%	0.18%
	Computer & Electrical Equipment	0.55%	0.02%	0.08%	0.45%	0.14%
	Motor Vehicles	0.98%	0.06%	0.09%	0.83%	0.25%
	Other Transportation Equipment	0.65%	0.05%	0.07%	0.53%	0.16%
	Miscellaneous Manufacturing	0.64%	0.02%	0.05%	0.57%	0.18%
Non-Manufacturing Industries	Agriculture	1.10%	0.49%	0.13%	0.48%	0.58%
	Forestry, Fishing, etc	0.41%	0.14%	0.02%	0.25%	0.21%
	Oil Mining	0.32%	0.09%	0.02%	0.21%	0.15%
	Gas Mining	0.32%	0.09%	0.02%	0.21%	0.15%
	Coal Mining	0.87%	0.49%	0.04%	0.34%	0.54%
	Other Mining Activities	1.15%	0.69%	0.04%	0.42%	0.73%
	Electric Utilities	9.10%	8.99%	0.00%	0.11%	8.96%
	Gas Utilities	0.21%	0.01%	0.01%	0.19%	0.08%
	Construction	0.70%	0.20%	0.02%	0.48%	0.35%
	Trade	0.33%	0.07%	0.06%	0.21%	0.13%
	Air Transportation	2.14%	1.89%	0.01%	0.24%	1.68%
	Truck Transportation	1.25%	0.92%	0.06%	0.27%	0.87%
	Other Transportation	0.78%	0.56%	0.01%	0.21%	0.55%
	Information	0.36%	0.03%	0.03%	0.30%	0.12%
	Finance and Insurance	0.17%	0.01%	0.02%	0.13%	0.06%
	Real Estate and Rental	0.37%	0.03%	0.15%	0.19%	0.11%
	Business Services	0.29%	0.08%	0.05%	0.16%	0.13%
	Other Services	0.40%	0.05%	0.07%	0.28%	0.14%
	Government	0.71%	0.38%	0.07%	0.26%	0.40%
	Average for EITE Industries (incl. petroleum refining)	1.37%	0.60%	0.20%	0.57%	0.70%

Source: Authors' calculations.

Table 4. Short Run Effect of 15/ton CO_2 Tax on Output (% change)

	Sector	Without Subsidies	With Subsidies
Manufacturing Industries	Food	-0.04%	-0.07%
	Textiles	-1.69%	-0.47%
	Apparel	1.11%	0.30%
	Wood & Furniture	-0.58%	-0.27%
	Pulp Mills	-0.08%	0.07%
	Paper Mills	-0.19%	0.07%
	Paperboard Mills	-0.43%	-0.24%
	Other Paper	-0.04%	0.00%
	Refining-LPG	-1.24%	-1.43%
	Refining-Other	-0.40%	-0.56%
	Petrochemicals	-1.23%	-0.20%
	Basic Inorganic Chemicals	-0.82%	0.00%
	Other Basic Organic Chemicals	-1.11%	-0.16%
	Plastics and Material Resins	-0.75%	-0.37%
	Artificial & Synthetic Fibers, Filaments	-0.51%	0.16%
	Fertilizer	-1.52%	-0.42%
	Other Chemicals & Plastics	-0.25%	-0.08%
	Glass Containers	-0.44%	0.13%
	Cement	-4.83%	-2.73%
	Lime and Gypsum	-2.33%	-1.82%
	Mineral Wool	-0.57%	-0.04%
	Other Nonmetallic Minerals	-0.57%	-0.29%
	Iron and Steel Mills and Ferroalloys	-0.46%	0.03%
	Alumina Refining, Primary & Secondary Aluminum	-2.37%	0.07%
	Ferrous Metal Foundries	-0.34%	-0.13%
	Non-Ferrous Metal Foundries	-1.22%	-0.23%
	Other Primary Metals	-1.49%	-0.31%
	Fabricated Metals	-0.29%	-0.03%
	Machinery	-0.79%	-0.17%
	Computer & Electrical Equipment	-0.95%	-0.25%
	Motor Vehicles	-0.50%	-0.11%
	Other Transportation Equipment	-0.47%	-0.11%
	Miscellaneous Manufacturing	-0.81%	-0.23%
Non-Manufacturing Industries	Agriculture	-0.29%	-0.24%
	Forestry, Fishing, etc	0.26%	0.02%
	Oil Mining	-1.48%	-2.19%
	Gas Mining	-16.73%	-16.61%
	Coal Mining	-33.33%	-33.45%
	Other Mining Activities	-0.17%	-0.13%
	Electric Utilities	-4.28%	-0.79%
	Gas Utilities	-1.09%	-0.24%
	Construction	-0.48%	-0.24%
	Trade	0.14%	0.02%
	Air Transportation	-0.43%	-0.49%
	Truck Transportation	-0.17%	-0.23%
	Other Transportation	0.01%	-0.11%
	Information	0.10%	0.02%
	Finance and Insurance	0.27%	0.07%
	Real Estate and Rental	0.10%	0.03%
	Business Services	0.09%	-0.01%
	Other Services	0.16%	0.03%
	Government	-0.48%	-0.27%
	Average for EITE Industries (incl. petroleum refining)	-0.46%	-0.24%

Source: Authors' calculations.

Table 5. Very-Short-Run vs. Short-Run Effects of $15/ton CO_2 Tax on Profits (% change)

		Without Subsidies		With Subsidies	
	Sector	Very Short-Run	Short-Run	Very Short-Run	Short-Run
Manufacturing Industries	Food	-10.30%	-0.04%	-4.20%	-0.07%
	Textiles	-17.11%	-1.69%	-4.77%	-0.47%
	Apparel	-3.40%	1.11%	-1.04%	0.30%
	Wood & Furniture	-7.99%	-0.58%	-3.33%	-0.27%
	Pulp Mills	-17.56%	-0.08%	-2.00%	0.07%
	Paper Mills	-9.34%	-0.19%	-0.64%	0.07%
	Paperboard Mills	-15.35%	-0.43%	-6.83%	-0.24%
	Other Papers	-9.38%	-0.04%	-2.44%	0.00%
	Refining-LPG	-17.61%	-1.23%	-8.33%	-1.43%
	Refining-Other	-11.80%	-0.39%	-5.58%	-0.56%
	Petrochemicals	-15.69%	-1.23%	-2.98%	-0.19%
	Basic Inorganic Chemicals	-33.46%	-0.81%	-2.32%	0.00%
	Other Basic Organic Chemicals	-54.51%	-1.07%	-9.43%	-0.15%
	Plastics and Material Resins	-22.87%	-0.72%	-9.85%	-0.36%
	Artificial & Synthetic Fibers, Filaments	-62.74%	-0.49%	-4.21%	0.16%
	Fertilizer	-78.73%	-1.52%	-22.05%	-0.42%
	Other Chemicals & Plastics	-3.75%	-0.23%	-1.14%	-0.08%
	Glass Containers	-9.08%	-0.44%	-0.01%	0.13%
	Cement	-17.64%	-2.12%	-0.59%	-0.02%
	Lime and Gypsum	-13.98%	-1.23%	-7.70%	-0.72%
	Mineral Wool	-7.13%	-0.57%	-0.73%	-0.04%
	Other Nonmetallic Minerals	-10.12%	-0.57%	-4.56%	-0.29%
	Iron and Steel Mills and Ferroalloys	-13.36%	-0.46%	-1.22%	0.02%
	Alumina Refining, Primary & Secondary Aluminum	-12.91%	-2.33%	0.01%	0.09%
	Ferrous Metal Foundries	-7.46%	-0.33%	-2.61%	-0.13%
	Non-Ferrous Metal Foundries	-16.44%	-1.22%	-3.42%	-0.23%
	Other Primary Metals	-9.45%	-1.45%	-2.06%	-0.30%
	Fabricated Metals	-7.02%	-0.29%	-1.26%	-0.03%
	Machinery	-6.18%	-0.79%	-1.37%	-0.17%
	Computer & Electrical Equipment	-7.87%	-0.95%	-2.07%	-0.24%
	Motor Vehicles	-21.22%	-0.50%	-5.35%	-0.11%
	Other Transportation Equipment	-4.30%	-0.47%	-1.04%	-0.11%
	Miscellaneous Manufacturing	-3.30%	-0.81%	-0.94%	-0.23%
Non-Manufacturing Industries	Agriculture	-3.05%	-0.27%	-1.62%	-0.23%
	Forestry, Fishing, etc	-1.46%	0.26%	-0.74%	0.02%
	Oil Mining	-0.55%	-1.49%	-0.26%	-2.20%
	Gas Mining	-0.55%	-16.81%	-0.26%	-16.70%
	Coal Mining	-2.92%	-33.49%	-1.80%	-33.62%
	Other Mining Activities	-3.38%	-0.16%	-2.15%	-0.13%
	Electric Utilities	-22.54%	-4.28%	-4.29%	-0.78%
	Gas Utilities	-1.06%	-1.02%	34.81%	-0.18%
	Construction	-3.81%	-0.47%	-1.89%	-0.24%
	Trade	-2.02%	0.14%	-0.81%	0.02%
	Air Transportation	-30.41%	-0.39%	-23.89%	-0.47%
	Truck Transportation	-6.07%	-0.15%	-4.26%	-0.22%
	Other Transportation	-4.03%	0.02%	-2.87%	-0.11%
	Information	-1.32%	0.10%	-0.45%	0.02%
	Finance and Insurance	-0.52%	0.27%	-0.19%	0.07%
	Real Estate and Rental	-0.65%	0.11%	-0.20%	0.03%
	Business Services	-1.36%	0.09%	-0.60%	0.00%
	Other Services	-2.74%	0.16%	-0.96%	0.03%
	Government	-6.72%	-0.47%	-3.76%	-0.27%
	Average for EITE Industries (incl. petroleum refining)	-11.82%	-0.44%	-3.83%	-0.23%

Source: Authors' calculations.

Table 6. Short-, Medium-, and Long-Run Effects of a $15/ton CO_2 Tax on Output (% change)

		Without Subsidies			With Subsidies		
	Sector	Short-Run	Medium-Run	Long-Run	Short-Run	Medium-Run	Long-Run
Manufacturing Industries	Food, Beverages, and Tobacco	-0.04	0.02	-0.10	-0.07	0.16	0.04
	Textiles	-1.69	-0.31	-0.31	-0.47	-0.10	-0.12
	Wearing Apparel and Leather	1.11	0.23	0.18	0.30	0.26	0.20
	Wood	-0.58	-0.31	-0.32	-0.27	-0.29	-0.31
	Paper and Publishing	-0.11	-0.18	-0.24	-0.01	0.20	0.13
	Petroleum and Coal Products	-0.44	-2.61	-3.27	-0.61	-1.89	-2.51
	Chemicals, Rubber, and Plastics	-0.50	-1.55	-1.52	-0.12	-0.46	-0.45
	Non-Metallic Mineral Products	-1.06	-1.07	-0.97	-0.59	-0.28	-0.19
	Ferrous Metals	-0.44	-1.00	-0.63	0.00	0.61	0.96
	Nonferrous primary metals	-1.69	-1.90	-1.35	-0.19	0.40	0.91
	Fabricated Metal Products	-0.29	-0.37	-0.28	-0.03	-0.16	-0.09
	Transportation Equipment	-0.49	-0.17	-0.18	-0.11	-0.11	-0.13
	Electronic equipment	-0.95	-0.20	-0.03	-0.25	-0.23	-0.08
	Machinery	-0.79	-0.12	0.08	-0.17	-0.17	0.00
	Other Manufacturing	-0.81	-0.12	0.22	-0.23	-0.10	0.19
Non-Manufacturing Industries	Agriculture	-0.29	0.06	-0.02	-0.24	0.01	-0.07
	Coal	-33.33	-13.86	-16.47	-33.45	-11.78	-14.25
	Oil mining	-1.48	-1.33	-1.93	-2.19	-1.22	-1.93
	Gas mining	-16.73	-2.48	-3.58	-16.61	-2.45	-3.49
	Other Minerals	-0.17	-0.99	-0.81	-0.13	-0.15	0.01
	Electric Utilities	-4.28	-3.81	-4.32	-0.79	0.69	0.18
	Gas manuf. and distribution	-1.09	-3.27	-3.48	-0.24	-0.83	-1.04
	Construction	-0.48	-0.36	-0.40	-0.24	-0.33	-0.37
	Trade	0.14	0.05	-0.07	0.02	0.24	0.12
	Transportation Services	-0.13	-1.26	-1.54	-0.22	-1.05	-1.32
	Communications	0.10	0.16	0.05	0.02	0.30	0.18
	Finance and Insurance	0.27	0.14	0.01	0.07	0.27	0.14
	Services (inc real estate)	0.12	0.02	-0.08	0.02	0.07	-0.02
	Owner-occupied Dwellings	-	0.49	0.28	-	0.77	0.57
	Average for EITE Inudstries (incl. petroleum refining)	-0.45	-0.90	-0.96	-0.19	-0.25	-0.31

Source: Author's calculations.

Table 7. Decomposition of Medium-Run Effects of a \$15/ton CO_2 Tax on Output (% change)

	Sector	Base Case Domestic Consumption (billion \$)	Without H.R. 2454 Subsidies: Δ in Output	Without H.R. 2454 Subsidies: Contribution (ΔQ=ΔU+ΔX-ΔM): Δ in Use	Without H.R. 2454 Subsidies: Contribution: Δ in Exports	Without H.R. 2454 Subsidies: Contribution: Δ in Imports	With H.R. 2454 Subsidies: Δ in Output	With H.R. 2454 Subsidies: Contribution (ΔQ=ΔU+ΔX-ΔM): Δ in Use	With H.R. 2454 Subsidies: Contribution: Δ in Exports	With H.R. 2454 Subsidies: Contribution: Δ in Imports
Manufacturing Industries	Food, Beverages, and Tobacco	685	0.02	0.06	-0.01	0.03	0.16	0.23	-0.02	0.05
	Textiles	147	-0.31	-0.14	-0.06	0.12	-0.10	0.09	-0.04	0.15
	Wearing Apparel and Leather	159	0.23	0.33	0.03	0.13	0.26	0.72	-0.01	0.45
	Wood	275	-0.31	-0.34	0.01	-0.03	-0.29	-0.23	-0.01	0.05
	Paper and Publishing	394	-0.18	-0.11	-0.05	0.02	0.20	0.17	0.02	-0.01
	Petroleum and Coal Products	310	-2.61	-2.26	-0.34	0.01	-1.89	-1.67	-0.25	-0.03
	Chemicals, Rubber, and Plastics	733	-1.55	-0.55	-0.79	0.21	-0.46	-0.09	-0.33	0.04
	Non-Metallic Mineral Products	123	-1.07	-0.47	-0.28	0.33	-0.28	-0.24	-0.04	0.00
	Ferrous Metals	150	-1.00	-0.48	-0.26	0.27	0.61	-0.10	0.32	-0.39
	Nonferrous primary metals	117	-1.90	-0.75	-0.84	0.32	0.40	-0.01	0.10	-0.31
	Fabricated Metal Products	303	-0.37	-0.33	-0.03	0.01	-0.16	-0.19	0.01	-0.02
	Transportation Equipment	766	-0.17	-0.22	0.02	-0.03	-0.11	-0.05	0.00	0.06
	Electronic equipment	561	-0.20	-0.26	-0.01	-0.07	-0.23	-0.18	-0.05	0.00
	Machinery	863	-0.12	-0.41	0.12	-0.17	-0.17	-0.25	0.02	-0.06
	Other Manufacturing	116	-0.12	0.16	0.00	0.28	-0.10	0.50	-0.10	0.50
Non-Manufacturing Industries	Agriculture	245	0.06	-0.01	0.07	0.00	0.01	0.08	-0.04	0.04
	Coal	39	-13.86	-15.90	1.44	-0.61	-11.78	-12.99	0.72	-0.48
	Oil mining	202	-1.33	-7.59	0.00	-6.26	-1.22	-5.51	0.00	-4.30
	Gas mining	36	-2.48	-4.71	6.51	4.28	-2.45	-3.05	6.19	5.59
	Other Minerals	32	-0.99	-0.99	-0.11	-0.11	-0.15	-0.17	-0.03	-0.05
	Electric Utilities	301	-3.81	-3.73	-0.09	0.00	0.69	0.66	0.03	0.00
	Gas manuf. and distribution	86	-3.27	-3.26	-0.01	0.00	-0.83	-0.88	0.04	0.00
	Construction	1,390	-0.36	-0.36	0.00	0.00	-0.33	-0.33	0.00	0.00
	Trade	2,420	0.05	0.04	0.00	0.00	0.24	0.24	0.00	0.00
	Transportation Services	789	-1.26	-0.74	-0.34	0.18	-1.05	-0.46	-0.37	0.22
	Communications	437	0.16	0.15	0.01	0.00	0.30	0.30	0.00	0.01
	Finance and Insurance	1,728	0.14	0.11	0.02	-0.01	0.27	0.28	0.00	0.01
	Services (inc real estate)	6,567	0.02	0.01	0.01	0.00	0.07	0.09	-0.01	0.01
	Owner-occupied Dwellings	1,188	0.49	0.49	0.00	0.00	0.77	0.77	0.00	0.00
	Average for EITE Industries (incl. petroleum refining)		-0.90	-0.49	-0.30	0.11	-0.25	-0.16	-0.10	0.00

Source: Author's calculations.

Table 8. Decomposition of Long-Run Effects of a \$15/ton CO_2 Tax on Output (% change)

	Sector	Base Case Domestic Consumption (billion \$)	Without H.R. 2454 Subsidies: Δ in Output	Without: Contribution (ΔQ=ΔU+ΔX-ΔM): Δ in Use	Without: Δ in Exports	Without: Δ in Imports	With H.R. 2454 Subsidies: Δ in Output	With: Contribution (ΔQ=ΔU+ΔX-ΔM): Δ in Use	With: Δ in Exports	With: Δ in Imports
Manufacturing Industries	Food, Beverages, and Tobacco	685	-0.10	-0.09	-0.01	0.01	0.04	0.09	-0.02	0.03
	Textiles	147	-0.31	-0.24	-0.06	0.01	-0.12	-0.02	-0.04	0.06
	Wearing Apparel and Leather	159	0.18	0.01	0.03	-0.13	0.20	0.42	-0.01	0.21
	Wood	275	-0.32	-0.43	0.01	-0.10	-0.31	-0.32	0.00	-0.01
	Paper and Publishing	394	-0.24	-0.21	-0.04	-0.01	0.13	0.06	0.03	-0.04
	Petroleum and Coal Products	310	-3.27	-2.94	-0.40	-0.07	-2.51	-2.30	-0.31	-0.10
	Chemicals, Rubber, and Plastics	733	-1.52	-0.67	-0.72	0.13	-0.45	-0.20	-0.27	-0.03
	Non-Metallic Mineral Products	123	-0.97	-0.51	-0.23	0.23	-0.19	-0.29	0.01	-0.09
	Ferrous Metals	150	-0.63	-0.33	-0.16	0.13	0.96	0.03	0.42	-0.51
	Nonferrous primary metals	117	-1.35	-0.50	-0.68	0.18	0.91	0.21	0.25	-0.45
	Fabricated Metal Products	303	-0.28	-0.34	0.00	-0.05	-0.09	-0.21	0.04	-0.08
	Transportation Equipment	766	-0.18	-0.37	0.05	-0.14	-0.13	-0.19	0.02	-0.04
	Electronic equipment	561	-0.03	-0.27	0.06	-0.18	-0.08	-0.20	0.01	-0.11
	Machinery	863	0.08	-0.48	0.26	-0.29	0.00	-0.32	0.14	-0.18
	Other Manufacturing	116	0.22	-0.19	0.16	-0.25	0.19	0.17	0.04	0.02
Non-Manufacturing Industries	Agriculture	245	-0.02	-0.10	0.05	-0.02	-0.07	0.00	-0.05	0.02
	Coal	39	-16.47	-17.35	0.35	-0.53	-14.25	-14.72	0.03	-0.44
	Oil mining	202	-1.93	-9.43	0.00	-7.50	-1.93	-7.22	0.00	-5.29
	Gas mining	36	-3.58	-8.05	1.36	-3.11	-3.49	-6.60	1.08	-2.03
	Other Minerals	32	-0.81	-0.88	-0.09	-0.15	0.01	-0.07	-0.01	-0.09
	Electric Utilities	301	-4.32	-4.23	-0.09	0.00	0.18	0.15	0.03	0.00
	Gas manuf. and distribution	86	-3.48	-3.47	0.00	0.00	-1.04	-1.09	0.05	0.00
	Construction	1,390	-0.40	-0.41	0.00	0.00	-0.37	-0.37	0.00	0.00
	Trade	2,420	-0.07	-0.08	0.00	-0.01	0.12	0.12	0.00	0.00
	Transportation Services	789	-1.54	-0.96	-0.39	0.18	-1.32	-0.68	-0.42	0.23
	Communications	437	0.05	0.02	0.02	-0.01	0.18	0.18	0.01	0.00
	Finance and Insurance	1,728	0.01	-0.02	0.02	-0.01	0.14	0.15	0.00	0.00
	Services (inc real estate)	6,567	-0.08	-0.10	0.01	-0.01	-0.02	-0.01	-0.01	0.00
	Owner-occupied Dwellings	1,188	0.28	0.28	0.00	0.00	0.57	0.57	0.00	0.00
	Average for EITE Industries (incl. petroleum refining)		-0.96	-0.64	-0.28	0.04	-0.31	-0.30	-0.07	-0.06

Source: Author's calculations.

Table 9. Decomposition of Long-Run Emissions Leakage Due to a $15 ton CO_2 Tax (1000 tons)

	Sector	Change in U.S. CO_2 Emissions	Change in Non-Annex I emissions				Leakage Rate (%)
			Due to:				
			Higher Exports to U.S.	Lower Imports from U.S.	Change in Carbon Intensity Differential	Total	
Manufacturing Industries	Food, Beverages, and Tobacco	-17,241	-8	0	-3	-11	-0.1
	Textiles	-3,639	4	11	-5	10	0.3
	Wearing Apparel and Leather	-1,448	-26	-3	2	-27	-1.9
	Wood	-4,627	-43	-3	-33	-79	-1.7
	Paper and Publishing	-24,537	27	43	52	121	0.5
	Petroleum and Coal Products	-10,495	1,125	647	1,074	2,846	27.1
	Chemicals, Rubber, and Plastics	-51,630	1,155	1,419	3,196	5,770	11.2
	Non-Metallic Mineral Products	-17,187	261	100	701	1,061	6.2
	Ferrous Metals	-15,843	457	142	586	1,186	7.5
	Nonferrous primary metals	-14,636	566	254	462	1,283	8.8
	Fabricated Metal Products	-4,496	-9	-2	-39	-50	-1.1
	Transportation Equipment	-7,253	-36	-16	-34	-86	-1.2
	Electronic equipment	-6,484	-89	-15	-18	-122	-1.9
	Machinery	-8,773	-106	-103	-296	-504	-5.7
	Other Manufacturing	-1,647	-12	-6	42	24	1.5
	Average for EITE Industries (incl. petroleum refining)						8.5

Authors' calculations.

Table 10. Long-Run Trade-Related Emissions Leakage Rates Due to a $15/ton CO_2 Tax

			Without Subsidies		With Subsidies	
		Subsidy Rates	Change in U.S. Emissions (1000 tons CO_2)	Leakage Rate	Change in U.S. Emissions (1000 tons CO_2)	Leakage Rate
Manufacturing Industries	Food, Beverages, and Tobacco	0.001%	-17,241	-0.1%	-14,680	0.1%
	Textiles	0.005%	-3,639	0.3%	-2,812	0.7%
	Wearing Apparel and Leather	0.000%	-1,448	-1.9%	-1,114	1.4%
	Wood	0.010%	-4,627	-1.7%	-3,657	-1.5%
	Paper and Publishing	0.157%	-24,537	0.5%	-20,052	-0.1%
	Petroleum and Coal Products	0.422%	-10,495	27.1%	-7,720	34.1%
	Chemicals, Rubber, and Plastics	0.241%	-51,630	11.2%	-40,274	9.2%
	Non-Metallic Mineral Products	0.489%	-17,187	6.2%	-15,087	2.6%
	Ferrous Metals	0.876%	-15,843	7.5%	-10,310	-3.7%
	Nonferrous primary metals	0.185%	-14,636	8.8%	-9,351	3.5%
	Fabricated Metal Products	0.000%	-4,496	-1.1%	-3,504	-2.5%
	Transportation Equipment	0.000%	-7,253	-1.2%	-5,725	-1.0%
	Electronic equipment	0.000%	-6,484	-1.9%	-5,126	-1.3%
	Machinery	0.000%	-8,773	-5.7%	-7,046	-4.7%
	Other Manufacturing	0.000%	-1,647	1.5%	-1,323	6.9%
	Average for EITE Industries (incl. petroleum refining)			8.5%		5.3%

Source: Author's calculations.

Table 11. Long-Run Aggregate Effects of Annex I Carbon Price Policies (% change)

	2004 CO_2 Emissions (mil. tons)	Without Subsidies in U.S.	With Subsidies in U.S.
Change in CO_2 Emissions			
US	6,070	-8.55%	-6.77%
Canada	566	-8.43%	-8.78%
Mexico	407	0.45%	0.38%
China	4,414	0.48%	0.41%
India	1,059	0.84%	0.77%
Rest of Annex I	7,669	-7.83%	-7.87%
Oil Exporters	1,994	1.42%	1.29%
Rest of the World	3,814	1.12%	1.02%
Total	25,994	-4.09%	-3.74%
Annex I Leakage Rate (%)		8.80%	8.69%
Decomposition of Change in U.S. Emissions			
Industry - Input substitution		62.4%	81.5%
Industry - Output level		24.4%	4.5%
Household		13.3%	13.9%
Decompostion of Change in Non-U.S. Emissions			
Industry - Input substitution		74.7%	72.8%
Industry - Output level		6.3%	8.6%
Household		19.0%	18.6%

Source: GTAP 7 data base and authors' calculations.