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International Trade and Carbon Leakage

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Abstract

Under a broad-based carbon tax or cap-and-trade program, some of the reduction in U.S. carbon dioxide emissions would probably be offset by increases in foreign emissions that would not otherwise have occurred, a phenomenon known as carbon leakage. Industries with substantial total emissions, high trade ratios, and high emission intensities are the most likely to generate substantial leakage. Therefore, the industries most likely to be sources of significant leakage through trade in their products are the chemical; primary metal (such as aluminum and iron and steel); and, to a lesser extent, the nonmetallic mineral products (cement, lime, gypsum, and glass) and petroleum and coal products (refining and coke production) industries. Under narrower programs targeting particular industries, significant leakage would occur in fewer industries.

Studies of economywide programs have produced estimates of leakage ranging from 1 percent to 23 percent of the emission reduction the programs would achieve in the countries implementing them. However, those estimates may not apply to future proposals, and estimating leakage is difficult and subject to considerable uncertainty.

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Under any policy to reduce carbon dioxide (CO_2) emissions that does not provide for subsidies sufficient to offset the cost of the reductions, some industries' or firms' production costs would increase, generally causing those industries or firms to raise the prices of the goods they produce. In the case of broad-based programs that cover all or almost all emissions, the prices of emission-intensive goods (that is, goods whose production requires the emission of large amounts of greenhouse gases relative to the goods' value) would increase the most. For more narrowly targeted programs, the prices of the products of the industries or firms targeted would increase the most. The higher prices would create incentives for other firms and consumers to purchase fewer of those goods, leading to declines in the production of those goods and the resulting emissions.

The higher costs would also make some U.S. producers less competitive relative to producers in countries that do not impose comparable emission-reduction policies. Therefore, some domestically produced goods would be displaced by foreign goods, and that displacement would cause some of the reduction in U.S. emissions to be offset by increases in foreign emissions that would not otherwise have occurred, a phenomenon known as carbon leakage.

Leakage can occur not only through trade but also through another mechanism, namely, through the price of carbon-based fuels. A U.S. emission-reduction program would reduce the use of carbon-based fuels in the United States. Because the fuels are internationally traded (primarily petroleum and, to a lesser extent, coal), the resulting reduction in demand would generally cause their prices in other countries to decline relative to what they would be otherwise. As prices dropped, demand for the fuels in other countries would rise; the amount of that increase would vary by fuel, depending on the ease with which it is traded and other factors. The resulting increase in use of the fuel in those countries would raise their emissions. This paper focuses on where in the economy leakage through trade is likely to be most significant and on the likely magnitude of the total leakage that would occur.

This analysis primarily discusses leakage that might occur under a tax on carbon dioxide emissions or a cap-and-trade program covering such emissions. To the extent that such policies also applied to other greenhouse gases (GHGs), they would be subject to leakage as well. For example, the agricultural sector is a significant source of methane, a potent greenhouse gas, and thus could be a source of leakage under a policy that taxed or applied caps to methane emissions.

Roughly two-thirds of U.S. GHG emissions and three-quarters of U.S. CO_2 emissions originate from the residential, commercial, construction, and transportation sectors. Aside from international air travel, those sectors face little international competition. Emission reductions achieved in those sectors would not be subject to being offset by carbon leakage through trade in the products of emission-intensive industries,

although they would be subject to leakage through reductions in the international prices of carbon-based fuels (especially petroleum).

The likely levels of leakage in the other sectors—agriculture, mining, and manufacturing—resulting from an economywide tax or cap placed on CO_2 emissions vary from industry to industry, depending on several factors. Particularly important are the following three:

- The industry's total CO_2 emissions;
- The amount of foreign competition, which can be roughly measured by the trade ratio (that is, the ratio of exports plus imports to U.S. market size); and
- The percentage increase in the industry's cost imposed by the program, which is likely to be roughly proportional to the industry's CO_2 emission intensity—one measure of which is the ratio of its direct emissions to its value added.

Industries with substantial total CO_2 emissions, high trade ratios, and high CO_2 emission intensities—such as the chemical, mining, and primary metals industries—are the most likely to generate substantial leakage under a broad-based carbon tax or cap-and-trade program that includes no provisions to reduce leakage.

Researchers have produced a number of estimates of the likely amounts of total leakage that would occur under various broad-based emission-reduction policies. Estimates of leakage from the studies that CBO reviewed range from 1 percent to 23 percent of the emission reduction the programs would achieve in the countries implementing them. Recently, a group of 12 modeling teams examined a policy consisting of a 20 percent reduction in emissions from their level in 2004 that was hypothetically implemented by a large group of industrialized countries that included the United States. The leakage rates projected by the modeling teams ranged from 5 percent to 19 percent, with a mean of 12 percent for the estimates. Estimates of leakage from the studies that CBO reviewed are generally for leakage that occurs long after the program begins. Leakage would probably be lower in the short term, and studies of programs in Europe have not found evidence of significant leakage in the first few years. Caution must be exercised in using the estimates to draw conclusions about other emission-reduction proposals, for reasons explained later in the paper.

The studies that produced the long-term estimates generally assumed that the emission-reduction programs included no provisions to mitigate the policies' effects on leakage. Many of them did not distinguish the modes of leakage—that is, through trade or energy prices. Those that did generally found

that leakage through energy prices would be more than half of the total leakage, but estimates of leakage through that mechanism are sensitive to the choice of values of some parameters (in particular, the sensitivity of coal production to the price of coal and the extent to which consumers are indifferent about where the coal is obtained) for which estimates in the literature are sparse and uncertain.

As a group, industries whose products are traded internationally produce only a small portion of GHG emissions in the United States. Hence, the loss of market share to foreign competitors and consequent percentage rates of leakage through trade could be much higher for some of those industries than for the economy as a whole. How those rates would compare with the estimated rates that are presented here for the economy, which include leakage through trade and leakage through the prices of carbon-based fuels, would depend on how much of the leakage occurs through fuel prices.

Determining Where Substantial Leakage Might Occur

For an economic sector or industry to be the source of substantial carbon leakage through trade in its products, it must:

- Produce sizable quantities of carbon dioxide;
- Have significant foreign competition not subject to the U.S. emission-reduction program or to an equivalent program implemented in its home country at the same time as the U.S. program; and
- Face a substantial percentage increase in its costs as a result of the emission-reduction program.

The following analysis pertains to an economywide carbon tax or cap-and-trade program. The analysis and conclusions assume that the emission-reduction program has no border adjustments or other provisions (such as transition assistance linked to changes in output or employment) that are designed to, or that might be expected to, prevent or ameliorate the reduction in competitiveness that causes the leakage.

The same industries identified by the analysis as likely sources of leakage would also be likely sources under a more narrowly focused carbon tax or cap-and-trade program to the extent that the program targeted those industries. If a program targeted only a subset of those industries, then only that subset would be a likely source of leakage.

Similarly, the same industries would be likely sources of leakage under standards regulating production processes to the extent that those standards targeted and raised the costs of those industries. If the standards targeted only a subset of the industries, then only that subset would be likely sources of leakage.

If the standards targeted other industries, less leakage would be likely to occur because either the amount of foreign competition or the emissions of those industries (or both) would be lower.

Significant leakage through trade would not be likely for standards regulating products, such as fuel economy standards for automobiles. The reason is that imported products would have to meet the same standards as domestically produced products, and exported domestic products would not have to meet the standards. Thus, the standards would not significantly affect the competitiveness of domestic production relative to foreign production and therefore would have little, if any, effect on trade. The analysis and conclusions in this paper do not apply to such standards.

The analysis and conclusions also do not apply to policies that include or take the form of subsidies. An example of such a subsidy is the tax credits under current law for the use of renewable sources of energy by producers of electricity.[1] Subsidies would offset the cost to firms of emission reduction and could result in lower rather than higher prices. Hence, their effects on trade could be different from the effects of other emission-reduction policies.

Broad Economic Sectors Not Subject to Trade-Related Leakage

To analyze the effects of emission-reduction programs, the most useful approach to quantifying the emissions of various parts of the economy is to attribute the emissions of the electrical generating sector (which accounted for 34 percent of all GHG emissions in the United States in 2010) to the other sectors or industries in proportion to their use of electricity and then adding those attributed emissions to the sectors' or industries' own emissions from production. The resulting sum for each sector or industry is commonly called its *direct emissions*.

The direct emissions of the transportation, residential, and commercial sectors accounted for about 62 percent of all GHG emissions in the United States in 2010—27 percent, 18 percent, and 17 percent, respectively (see Table 1). Those sectors face little foreign competition that would not be covered by a U.S. emission-reduction program.[2] They would therefore not be a source of leakage through trade in their products. The same is true for the construction sector, but a separate estimate of that sector's GHG emissions was not available.

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[1] For additional information, see the testimony of Terry M. Dinan, Senior Advisor, Congressional Budget Office, before the Subcommittee on Energy of the House Committee on Science, Space, and Technology, *Federal Financial Support for Fuels and Energy Technologies* (March 13, 2013), www.cbo.gov/publication/43993.

[2] Domestic airlines face foreign competition on international flights, but foreign airlines departing from U.S. airports would have to purchase fuel in the United States and would therefore incur the cost of higher prices for such fuel resulting from a carbon tax or a cap-and-trade program.

Table 1.
Direct Emissions of Greenhouse Gases, by U.S. Economic Sector, 2010

(Percent)

Sector	All Greenhouse Gases	Carbon Dioxide Only
Agriculture	8	1
Mining, Construction, and Manufacturing	30	29
Transportation	27	31
Residential	18	21
Commercial	17	18
Total	**100**	**100**

Source: Congressional Budget Office based on estimates of greenhouse gas and carbon dioxide emissions from Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2010*, EPA 430-R-12-001 (April 2012), p. 2-19, Table 2-14, http://go.usa.gov/T8mj.

Notes: A sector's direct emissions are the sum of its emissions and the emissions attributable to the production of the electricity it uses.

The data source includes separate estimates for the emissions from U.S. territories. CBO excluded those estimates when calculating the numbers in this table.

The same four sectors—transportation, residential, commercial, and construction—produced 72 percent of CO_2 emissions in the United States. The agricultural, mining, and manufacturing sectors, which account for 28 percent of CO_2 emissions, produce goods that are traded internationally and therefore could become sources of carbon leakage through trade (that total excludes emissions from the construction industry from the total reported in Table 1 for emissions from mining, construction, and manufacturing).[3] The rest of this section discusses which industries in those sectors would probably generate the most carbon leakage through trade.

Analysis of the Agriculture, Mining, and Manufacturing Sectors

Within the sectors that face international competition, the likelihood of sizable leakage varies substantially among industries because of differences in the extent of their emissions, the foreign competition they face, and the amounts by which an emission-reduction program would raise their costs.

[3] The sources for Table 1 similarly did not contain an estimate of the CO_2 emissions of the construction sector, but CBO was able to estimate those emissions at 2 percent of the U.S. total using estimates of industry emissions for 2006 from Department of Commerce, Economics and Statistics Administration, *U.S. Carbon Dioxide Emissions and Intensities Over Time: A Detailed Accounting of Industries, Government and Households* (April 2010), http://go.usa.gov/T8P9; estimates of sector emissions for 2006 and 2010 from Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2010*, EPA 430-R-12-001 (April 2012), p. 2-19, Table 2-14, http://go.usa.gov/T8mj; and industry value-added, output, and price data from the Bureau of Economic Analysis. The estimate of 28 percent for the agricultural, mining, and manufacturing sectors is derived from the numbers in the table and the estimate of 2 percent for the construction sector.

The industries most likely to experience large effects under an emission-reduction program can be identified by considering each of those characteristics in turn.

Industries With Large Emissions. Of the 23 industries in the agricultural, mining, and manufacturing sectors, each of the top nine emitters (ranked by direct emissions) was the source of between 1 percent and 6 percent of direct emissions of CO_2 in the United States in 2010. Those industries are petroleum and coal products (refining); chemicals; mining; primary metals; nonmetallic mineral products; food; agriculture, forestry, and fisheries; paper; and computer and electronic products (see Table 2). Each of the bottom nine emitters produced only 0.3 percent or less. Hence, all else being the same, the top nine emitters would be much more likely to be the source of sizable leakage through trade in their products than would the bottom nine.

Examining industries' *total emissions* of CO_2—that is, direct emissions plus the emissions entailed in producing the intermediate inputs the industries purchase for producing their goods—does not change the picture much. The nine industries with the largest emissions are mostly the same; the rank order shifts slightly, and the paper industry is replaced by the transportation equipment industry. Each industry was the source of between 1.8 percent and 8.5 percent of total emissions of CO_2 in the United States.

The analysis presented here focuses on CO_2 emissions because of a lack of data for other GHG emissions at the industry level. Carbon dioxide makes up more than four-fifths of GHG emissions in the United States, however, so the numbers for CO_2 emissions should be similar to those for GHG emissions for most industries. A notable exception is the agriculture, forestry, and fisheries industry, whose direct emissions accounted for only 1.5 percent of all CO_2 emissions in the United States in 2010 but for 7.7 percent of all GHG emissions in that year. The discrepancy arises because 84 percent of the industry's GHG emissions were gases other than CO_2 (mostly methane and nitrous oxide).[4] The cap-and-trade proposals the Congress has considered have not capped any of the non-CO_2 greenhouse gas emissions of that industry. Hence, the likelihood of sizable carbon leakage in that industry under the proposed programs would be a function of the sector's emissions of CO_2, which are not particularly high, rather than a function of its higher emissions of all greenhouse gases. However, if the United States were to tax or place a cap on emissions of methane and nitrous oxide in addition to CO_2, significant leakage could occur in the agricultural sector.

[4] That percentage is based on data from Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2010* (April 2012), Table 2-14, pp. 2-19 to 2-20, http://go.usa.gov/T8mj.

Table 2.
CO_2 Emissions in the U.S. Agricultural, Mining, and Manufacturing Sectors, by Industry, 2010

(Percentage of all CO_2 emissions)

Industry	Direct Emissions[a]	Total Emissions[b]
Petroleum and Coal Products	6.2	8.5
Chemicals	4.5	5.9
Mining	3.4	3.7
Primary Metals	2.7	3.1
Nonmetallic Mineral Products	2.1	2.3
Food	1.7	3.8
Agriculture, Forestry, and Fisheries	1.5	2.1
Paper	1.1	1.4
Computer and Electronic Products	1.0	2.1
Plastic and Rubber Products	0.8	1.5
Fabricated Metal Products	0.7	1.4
Transportation Equipment	0.6	1.8
Machinery	0.6	1.7
Wood Products	0.4	0.7
Textile Mills	0.3	0.3
Electrical Equipment, Appliances, and Components	0.2	0.5
Printing and Related Support	0.2	0.5
Miscellaneous Manufacturing	0.2	0.6
Beverage and Tobacco Products	0.2	0.7
Furniture and Related Products	0.1	0.3
Textile Mill Products	0.1	0.2
Apparel	*	0.1
Leather and Allied Products	*	*

Source: Congressional Budget Office estimates based on data for industry emissions in 2006 from Department of Commerce, Economics and Statistics Administration, *U.S. Carbon Dioxide Emissions and Intensities Over Time: A Detailed Accounting of Industries, Governments and Households* (April 2010), http://go.usa.gov/T8P9; data for sector emissions in 2006 and 2010 from Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2010*, Report No. 430-R-12-001 (April 2012), p. 2-19, Table 2-14, http://go.usa.gov/T8mj; and industry value-added, output, and price data from the Bureau of Economic Analysis.

Note: CO_2 = carbon dioxide; * = between zero and 0.05 percent.

a. An industry's direct emissions are the sum of its emissions and the emissions attributable to the production of the electricity it uses.

b. An industry's total emissions are the sum of its direct emissions and the emissions attributable to the production of the intermediate inputs it uses.

Industries That Have Substantial International Competition. The extent of foreign competition an industry faces can be roughly measured by the dollar values of its imports and exports relative to the size of the U.S. market. For a number of reasons, those ratios are imperfect indicators of the degree of competition. For example, some industries ship parts produced in the United States to low-wage countries such as Mexico or China for labor-intensive final assembly and then import the assembled products back to the United States. In such cases, the exports, imports, and domestic production may all be classified as belonging to the industry in question, leading to high trade values for the industry; yet the factories supplying the imports are not competing with U.S. producers. Nevertheless, a comparatively high ratio of imports or of exports to the size of the U.S. market indicates that a good is more easily traded than are other goods, thereby raising the possibility that an emission-reduction program might lead to a loss in market share and subsequent carbon leakage for the industry producing the good.

Comparatively low ratios of imports and of exports of a good suggest that it is less easily or economically traded than are other goods and that little leakage is therefore likely to result from trade in that good.

As measured by U.S. trade with all countries, a large fraction of the 23 industries in the agricultural, mining, and manufacturing sectors face sizable foreign competition. Eleven of the industries—leather and allied products; apparel; machinery; computer and electronic products; electrical equipment, appliances, and components; miscellaneous manufacturing; transportation equipment; textile mills; chemicals; primary metals; and textile mill products—have *total trade* (exports plus imports) exceeding 50 percent of their respective U.S. market sizes (see Table 3).

One might argue that an industry's trade with all countries is not the best measure to use for assessing the likelihood of significant leakage. If all or most of the industry's foreign competitors were in countries that imposed comparable emission-reduction programs of their own, those competitors would face increases in cost similar to those faced by firms in the U.S. industry. Consequently, the competitiveness of the U.S. industry would change little if at all. Therefore, the argument would go, a better indicator of competition might be trade with countries that are unlikely to impose comparable emission-reduction programs of their own.

Although one can make counterarguments, the proposed alternative measure is nevertheless informative. It is not possible to predict with confidence which U.S. trading partners would adopt comparable policies, but a country's not having signed on to Annex II of the U.N. Framework Convention on Climate Change may be taken as an indicator that the country is less likely to implement comparable policies than is a

Table 3.
Ratio of U.S. Trade to U.S. Market Size in the Agricultural, Mining, and Manufacturing Sectors, by Industry, 2010

(Percent)

	Trade With All Countries			Trade With Non-Annex II Countries[a]		
Industry	**Exports**	**Imports**	**Total**	**Exports**	**Imports**	**Total**
Leather and Allied Products	7	96	103	5	93	97
Apparel	3	87	91	2	86	87
Machinery	43	38	80	27	16	43
Computer and Electronic Products	20	57	77	13	48	62
Electrical Equipment, Appliances, and Components	21	46	67	12	36	48
Miscellaneous Manufacturing	18	47	65	7	35	43
Transportation Equipment	27	37	64	14	15	28
Textile Mills	30	26	56	24	17	41
Chemicals	27	28	55	13	10	23
Primary Metals	20	32	52	8	17	25
Textile Mill Products	7	45	52	3	42	45
Mining	4	38	42	2	29	31
Furniture and Related Products	4	33	38	1	29	31
Plastic and Rubber Products	13	19	32	6	12	18
Agriculture, Forestry, and Fisheries	19	13	32	13	10	23
Fabricated Metal Products	11	17	28	6	10	16
Nonmetallic Mineral Products	9	18	27	4	12	16
Paper	13	13	27	7	4	12
Petroleum and Coal Products	9	15	24	7	10	17
Wood Products	7	17	23	3	8	11
Beverage and Tobacco Products	4	12	15	2	4	5
Food	8	6	14	5	3	8
Printing and Related Support	7	6	13	2	4	6

Source: Congressional Budget Office based on trade data from the Bureau of the Census and input-output data from the Bureau of Economic Analysis.

Note: The U.S. market for each industry is defined as U.S. industry output plus imports minus exports. Export numbers are free-alongside-ship values (the value of a commodity at the port of exportation, generally including the purchase price plus all charges incurred in placing the commodity alongside the carrier at the port of exportation in the country of exportation). Import numbers are cost, insurance, and freight (sometimes referred to as CIF) values. Industry output data are from the use tables of the input-output accounts published by the Bureau of Economic Analysis.

a. Countries that signed Annex II of the U.N. Framework Convention on Climate Change thereby agreed to an additional provision of the convention requiring those countries to provide financial resources to cover the costs incurred by developing countries in meeting their obligations under the convention. Non-Annex II countries—that is, countries that did not sign Annex II—might be considered less likely than Annex II countries to implement emission-reduction programs comparable with one that the United States might implement.

signatory country.[5] That list, however, is only a rough indicator. Some countries that signed Annex II ultimately may not undertake action, and some that did not sign Annex II may undertake action.

A further qualification to the use of a country's signing or not signing onto Annex II as such an indicator is that some signatories—notably the European Union (EU), Australia, and New Zealand—have already begun (or have decided to begin) implementing emission-reduction programs. Therefore, if the United States implemented a program, those countries would not be doing so at the same time as the United States. In the absence of a U.S. program, the programs in those countries could be expected to cause (and may in some cases already be causing) changes in U.S. trade with those countries that would create leakage for those programs. That is, U.S. exports of the products of emission-intensive industries to those countries would increase and imports of such products would decline—the opposite of what would result from a U.S. emission-reduction program. If the United States then implemented such a program, those changes in trade would be reversed. The competitiveness of U.S. firms in emission-intensive industries would decline relative to the competitiveness of firms in those countries, and leakage would occur, compared with the status quo in which the other countries were implementing their programs but the United States was not.

Competitiveness would not decline, however, nor would any leakage occur compared with what would be the case if neither the United States nor the other countries implemented programs.

That qualification being noted, roughly the same industries stand out as having more international competition than the others regardless of whether the competition is measured by trade with all countries or by trade with non-Annex II countries (see Table 3). The two industries with the highest trade ratios—leather and allied products and apparel—have values of trade with non-Annex II countries that are not much lower than the values with the world as a whole, which indicates that almost all of the foreign competition for the industries is in countries less likely than others to implement their own emission-reduction programs. For the rest of the industries in the top 11 (those whose ratios of trade with the world to U.S. market size are at least 50 percent), the differences between trade with all countries and trade with

[5] U.N. Framework Convention on Climate Change (UNFCCC), May 9, 1992, 1771 U.N.T.S. 107, http://tinyurl.com/cq9dxdm. Thirty-eight countries signed Annex I to the convention, thereby agreeing to limit their emissions in accordance with the convention. Twenty-three of those countries, generally the advanced industrialized countries, also signed Annex II, thereby agreeing to an additional provision requiring that they provide financial resources to cover the costs incurred by developing countries in Annex I in meeting their obligations under the convention. The Kyoto Protocol to the UNFCCC, Dec. 11, 1997, 2303 U.N.T.S. 148, specified more precise commitments for its signatories, which are listed in Annex B of the protocol. The list of countries is identical to the list in Annex I of the UNFCCC except for Belarus and Turkey, both of which are listed in Annex I but not in Annex B of the Kyoto Protocol.

non-Annex II countries are larger—much larger in a number of cases—although trade with non-Annex II countries is still sizable enough to allow some leakage to occur.

Industries with both sizable CO_2 emissions and large ratios of trade to U.S. market size include the chemicals, mining, primary metals, and computer and electronic products industries. (Mining ranks 12th in the ratio for trade with the world, but 9th—above chemicals and primary metals—for trade with non-Annex II countries.) Compared with those four industries, the machinery and transportation equipment industries have trade ratios that are similarly large but emissions that are somewhat lower; the agriculture, forestry, and fisheries industry has similarly large emissions but somewhat smaller trade ratios; and the petroleum and coal products (refining and coke production) industry and the nonmetallic mineral products industry have sizable emissions but even smaller trade ratios.

Product and industry characteristics raise the likelihood of significant leakage in the chemicals and primary metals industries relative to that in the transportation equipment and computer and electronic products industries. The chemicals and primary metals industries tend to produce fairly homogeneous products, giving purchasers little reason to care whether they buy U.S. products or competing products made by foreign producers. That fact would suggest a higher likelihood of significant leakage. By contrast, the products of the transportation equipment industry and possibly the computer and electronic products industry are more heterogeneous, which may reduce the likelihood of significant leakage. Those two industries also in some cases assemble products in some countries from parts produced in other countries, which may inflate the trade ratios.

Industries Whose Costs Would Rise Substantially. Simply having sizable emissions and significant exposure to foreign competition would not necessarily cause an industry to become less competitive as a result of an emission-reduction program. An industry with significant foreign competition would suffer competitively in proportion to the percentage by which its costs increased as a result of the program. Under a program that imposed costs on all or almost all CO_2 emissions—such as an economywide carbon tax or cap-and-trade program—industries' costs would increase by an amount that is proportional to CO_2 emissions, so a large quantity of emissions would mean a large increase in costs.

Note, however, that the quantity of an industry's emissions might be large simply because the industry itself is large, has a sizable output, and therefore has high total costs. In that case, the percentage increase in cost would be large only if the industry's CO_2 emissions were high relative to the value of its output—that is, if it had a high *emission intensity*.

Two measures of emission intensity are relevant:

- The *direct emission intensity* is the ratio of the sum of direct emissions from fossil-fuel combustion, process emissions, and emissions from electricity consumed by the industry to the value added by the industry.[6]
- The *total emission intensity* is the ratio of the sum of the components of direct emission intensity and emissions from the production of intermediate inputs used by the industry to the value of the industry's gross output.

Which measure is more relevant for a given industry depends on how widespread the emission-reduction program is (for example, whether it affects only the industry or both the industry and its suppliers). It also depends on whether the intermediate inputs are easily traded, and, if they are, whether significant suppliers of the inputs are located in countries not imposing their own emission-reduction programs (or are likely to be located in such countries in the future). However, the industries in the agricultural, mining, and manufacturing sectors with the highest CO_2 emission intensities are the same by either measure, although ordered a bit differently: primary metals, nonmetallic mineral products, petroleum and coal products, textile mills, paper, chemicals, wood products, and mining (see Table 4).

The industries most likely to incur significant leakage are those with sizable emissions, sizable foreign competition, and high emission intensities. The chemicals and primary metals industries have those characteristics (see Figure 1). Petroleum and coal products and nonmetallic mineral products industries produce large quantities of CO_2 emissions and have high emission intensities, but they have less competition as measured by trade.

Estimates of Leakage

A number of studies have estimated carbon leakage for various economywide emission-reduction programs. Those studies can be grouped into three categories:

- Recent studies that used economic models to project leakage in the long term for specific proposals for reducing U.S. emissions;
- Earlier studies of the Kyoto Protocol that used economic models to project leakage for that agreement; and

[6] *Process emissions* are emissions from a production process other than those that result from the consumption of carbon-based fuels. The *value added by an industry* is the value of its output minus the value of the intermediate inputs it purchases from other industries for its production process.

Table 4.
CO_2 Emission Intensities in the U.S. Agricultural, Mining, and Manufacturing Sectors, by Industry, 2010

Industry	Direct Intensity[a]	Total Intensity[b]
Primary Metals	3.6	0.8
Nonmetallic Mineral Products	3.3	1.5
Petroleum and Coal Products	2.0	0.7
Textile Mills	1.8	0.7
Paper	1.1	0.5
Chemicals	1.1	0.5
Wood Products	1.0	0.6
Mining	0.8	0.5
Plastic and Rubber Products	0.6	0.5
Food	0.6	0.3
Agriculture, Forestry, and Fisheries	0.5	0.3
Textile Mill Products	0.4	0.4
Printing and Related Support	0.3	0.3
Fabricated Metal Products	0.3	0.3
Transportation Equipment	0.3	0.2
Electrical Equipment, Appliances, and Components	0.3	0.2
Machinery	0.2	0.3
Computer and Electronic Products	0.2	0.3
Furniture and Related Products	0.2	0.3
Beverage and Tobacco Products	0.2	0.3
Apparel	0.2	0.3
Leather and Allied Products	0.2	0.4
Miscellaneous Manufacturing	0.1	0.2

Source: Congressional Budget Office estimates based on data for industry emissions in 2006 from Department of Commerce, Economics and Statistics Administration, *U.S. Carbon Dioxide Emissions and Intensities Over Time: A Detailed Accounting of Industries, Governments and Households* (April 2010), http://go.usa.gov/T8P9; data for sector emissions in 2006 and 2010 from Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2010*, EPA 430-R-12-001 (April 2012), p. 2-19, Table 2-14, http://go.usa.gov/T8mj; and industry value-added, output, and price data from the Bureau of Economic Analysis.

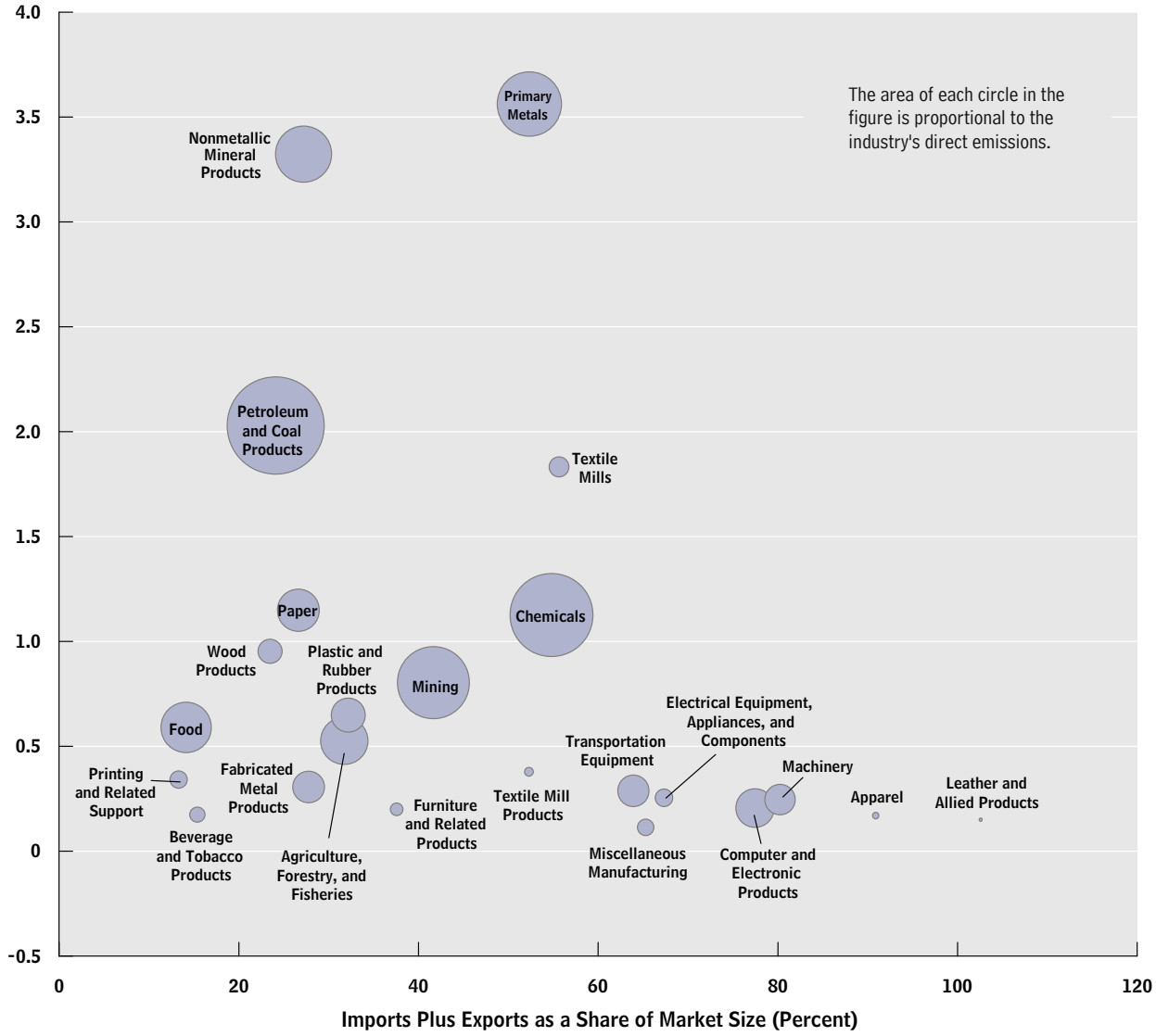
Note: CO_2 = carbon dioxide.

a. An industry's direct intensity is the ratio of its direct emissions to its value added—that is, to the value of its output minus the value of the intermediate inputs it uses to produce the output. (Direct emissions are the sum of the industry's emissions and the emissions attributable to the production of the electricity it uses.) Direct intensity is measured here in metric tons of CO_2 per thousand dollars of value added.

b. An industry's total intensity is the ratio of its total emissions to the value of its output. (Total emissions are the sum of an industry's direct emissions and the emissions attributable to the production of the intermediary inputs it uses.) Total intensity is measured here in metric tons of CO_2 per thousand dollars of total output.

Figure 1.
Carbon Dioxide Emission Intensities, International Trade, and Emissions, by Industry, 2010

(Carbon dioxide emission intensity)



Source: Congressional Budget Office.

Notes: The largest amounts of leakage through trade are likely to occur in industries that have sizable emissions of carbon dioxide (CO_2), have high direct emission intensities, and face significant foreign competition as measured by the ratio of an industry's trade—imports plus exports—to the size of the U.S. market. The size of the U.S. market for each industry is measured here by the industry's output plus imports minus exports. As such, the ratio can exceed 100 percent.

Direct CO_2 emissions are the sum of an industry's own emissions and the emissions attributable to the production of the electricity it uses.

The CO_2 emission intensity shown is the direct intensity, which is the ratio of an industry's direct emissions to its value added (that is, to the value of its output minus the value of the intermediate inputs it uses), measured here in metric tons of CO_2 per thousand dollars of value added.

- Several studies that used other methodologies to determine the leakage that occurred in the first few years after emission-reduction programs were implemented in Europe and one study that examined the effects on trade of changes in energy prices in the United States that were equivalent in effect to imposing a carbon tax.

Caution must be exercised in using the estimates from such studies to draw conclusions about other proposals, for several reasons. First, estimates of leakage are subject to considerable uncertainty, in part because analysts must make assumptions about important factors about which there is insufficient knowledge. Second, the reduction in competitiveness of U.S. producers and the consequent amount of leakage that would result from an emission-reduction policy would depend on the actions of other countries. For example, if all major U.S. trading partners implemented their own equivalent policies, then an emission-reduction program would not substantially reduce the competitiveness of U.S. producers, and the carbon leakage that would occur through international trade would be relatively small; to the extent that major trading partners did not implement their own policies, the decline in competitiveness and the resulting carbon leakage would be larger. Third, leakage would probably be low in the first few years after a program started and would grow over time. Fourth, the estimates above are for economywide emission-reduction programs such as a carbon tax or a cap-and-trade program. Narrower programs—such as a cap-and-trade program for electric utilities only, production efficiency standards for selected industries, or standards setting minimum requirements for use of renewable fuels by some industries—could have higher or lower rates of leakage, depending on whether the industries or economic sectors they targeted were among those likely to constitute significant sources of leakage. Finally, the estimates generally do not account for policies that are designed to reduce leakage or that would reduce leakage as one of their effects. Examples of such policies are border adjustments, such as tariffs or subsidies, or transition assistance that is linked to continuing levels of output or employment by the firm receiving it.

Forward-Looking Estimates for U.S. Emission-Reduction Proposals

Several studies have used general-equilibrium modeling to project the amount of leakage that would occur in the long term under various proposals for reducing U.S. emissions.

An analysis by the Environmental Protection Agency (EPA) examined the potential for reduced competitiveness and carbon leakage resulting from the cap-and-trade program for U.S. emissions contained in the Climate Security Act of 2008 (S. 2191).[7] In one scenario, EPA assumed that U.S. efforts

[7] Environmental Protection Agency, *EPA Analysis of the Lieberman-Warner Climate Security Act of 2008, S. 2191 in 110th Congress* (March 14, 2008), http://go.usa.gov/T8VR (PDF, 4 MB). S. 2191 was reported from the Senate Committee on Environment and Public Works on May 20, 2008, but no further action was taken on the bill.

to lower GHG emissions would be mirrored by all signatories to the Kyoto Protocol except Russia but that all other countries would take no action. The analysis estimated the likely carbon leakage at values near 10 percent in 2030 and 2050.

Another study estimated leakage under a tax of $15 per ton of CO_2 imposed by all Annex I countries.[8] (Annex I countries are the 38 countries that agreed to limit their emissions in accordance with the U.N. Framework Convention on Climate Change.) The study projected a long-run leakage rate of 9 percent average over all Annex I countries. It projected the largest leakage rates among manufacturing industries to be for the petroleum and coal products industry (27 percent); the chemicals, rubber, and plastics industries (11 percent); the nonferrous primary metals industry (9 percent); the ferrous metals industry (8 percent); and the nonmetallic mineral products industry (6 percent). Those rates reflect the percentage of the reduction in emissions in each industry that would be offset by increased emissions by competitors in foreign countries.

The same study also addressed the question of how much of total leakage would occur through trade in emission-intensive goods compared with how much how much would occur as a result of the reduction in international prices of carbon-based fuels. That question is important because leakage by the latter mechanism cannot be eliminated or even reduced by measures regulating international trade (aside from a prohibition on the export of coal). A survey of studies estimating leakage for the Kyoto accords (discussed below) noted that there is little empirical evidence on the issue. It noted further that most modelers seem to agree that the energy-price channel is the most important in the short to medium run but that trade in emission-intensive goods might become dominant in the long run as a result of changes in the destination of international investment and the relocation of industries.[9]

Another survey of studies (including studies of European and possible U.S. programs) stated, “In virtually all applied economic models incorporating both channels, the larger part of carbon leakage occurs

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[8] See Liwayway Adkins and others, *Carbon Pricing With Output-Based Subsidies: Impact on U.S. Industries Over Multiple Time Frames*, RFF DP 12-27 (Resources for the Future, June 2012), http://tinyurl.com/lnn2d6s. The study also presents estimates for leakage that would occur if output-based subsidies equivalent to the transition assistance that would be granted under H.R. 2454, the American Clean Energy and Security Act of 2009, were allocated to industries. Those estimates are not presented here, in part because the purpose of this section is to indicate the likely magnitude of leakage if nothing was done to counteract it and in part because the effects of such subsidies on leakage *rates* (as opposed to absolute amounts of leakage) are different for a carbon tax than for a cap-and-trade program.

[9] J.P.M. Sijm and others, *Spillovers of Climate Policy: An Assessment of the Incidence of Carbon Leakage and Induced Technological Change Due to CO_2 Abatement Measures*, Report 500036-002 (Netherlands Research Programme on Climate Change, December 2004), pp. 13–14 and 31, http://tinyurl.com/lh3f3pw (PDF, 1.29 MB).

through this fossil fuel channel, rather than via the competitiveness channel …"[10] The survey cited five studies to support that statement. Estimates from the study of a tax of $15 per ton of CO_2 are consistent with the statement. The study estimated that 6 percent of the increase in emissions of other countries would be attributable to greater industry output in those countries (leakage through international trade) and that the rest would be attributable either to increased emissions by households or to increased emissions of industry per unit of output (leakage through the price of carbon-based fuels).

Estimates of leakage through the price of carbon-based fuels are sensitive to the values assumed for various parameters in the economic model used to produce the estimates, and the correct values of some of those parameters are not known with much accuracy. One study used a simplified version of a model in the literature to examine the sensitivity of leakage estimates to the assumed values of various parameters.[11] Burniaux and Martins found that estimates of leakage through energy prices were particularly sensitive to the assumed sensitivity of coal production to the price of coal and to the assumed extent to which purchasers of coal were indifferent to its origin—that is, their assumed willingness to switch to coal from another country in response to relative price changes. Thus, if the amount of coal produced was not sensitive to price, a decline in the demand for coal in, for example, the United States as a result of an emission-reduction program would lead to a domestic surplus of coal and a consequent decline in its price. If purchasers in other countries were relatively indifferent about the origins of coal (whether from the United States or some other location), the now-lower U.S. price would prompt them to purchase the surplus U.S. coal, resulting in sizable leakage. However, if the amount produced was sensitive to the price, then the decline in demand in the United States would lower the price of coal, and, in response, the amount of coal produced would decline, resulting in little leakage.

Burniaux and Martins also reviewed the literature for estimates of the sensitivity of production to price and found that such estimates were sparse and mixed.[12] They concluded that leakage is likely to be small for the range of parameters most frequently quoted in the literature but argued that further empirical work was needed on that issue.

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[10] ZhongXiang Zhang, *Competitiveness and Leakage Concerns and Border Carbon Adjustments*, Working Papers in English 2012.080 (Fondazione Eni Enrico Mattei, 2012), p. 3, http://tinyurl.com/clzqb5z.

[11] Jean-Marc Burniaux and Joaquim Oliveira Martins, *Carbon Emission Leakages: A General Equilibrium View*, Working Paper 242 (Organisation for Economic Co-operation and Development, May 2000), http://tinyurl.com/p5tzn4c (PDF, 548 KB).

[12] See Adkins and others, *The Impact on U.S. Industries of Carbon Prices With Output-Based Rebates Over Multiple Time Frames*.

Still another study CBO examined estimated the likely leakage from the emission-reduction program in the proposed American Clean Energy and Security Act of 2009 (H.R. 2454).[13] That bill contained provisions to offset the effects of the program on the competitiveness of industries. The study found that without those provisions the leakage through trade in the products of "trade vulnerable" industries would be on the order of 10 million metric tons of CO_2 equivalent, or about 10 percent of the estimated emission reductions achieved in those industries, compared with leakage of about 1 million metric tons (or about 1 percent) with those provisions. Those numbers cannot be compared with the other numbers presented here for at least three reasons. First, they are only for a subset of all industries, not for the economy as a whole. Second, they include only leakage through trade and not leakage through the prices of carbon-based fuels. Third, the estimates are for what the study calls the medium term, whereas the other estimates presented here are for the long term. The study does not present any estimates for leakage through both mechanisms for the entire economy.

Forward-Looking Estimates of Leakage Under Multinational Emission-Reduction Proposals

Recently, a group of 12 modeling teams projected the leakage that would occur in one particular emission-reduction policy.[14] The policy consisted of a 20 percent reduction in emissions from their level in 2004 that the modelers assumed would be implemented by industrialized countries as listed in Annex I of the U.N. Framework Convention on Climate Change, including the United States but not the Russian Federation. The leakage rates projected by the 12 teams ranged from 5 percent to 19 percent, with a mean of 12 percent for the 12 estimates.

The estimates are sensitive to the size of the coalition of countries assumed to implement the emission-reduction policy. When China was added to the coalition, the mean leakage estimate was only 7 percent rather than 12 percent. When the coalition was reduced to consist only of the countries of the EU and the European Free Trade Area, the mean leakage estimate was 24 percent.

The estimates are also sensitive to what is assumed about the behavior of oil-producing countries. When those producers were assumed to counteract the decline in fuel prices by restricting their output, the mean

[13] Environmental Protection Agency, *The Effects of H.R. 2454 on International Competitiveness and Emission Leakage in Energy-Intensive Trade-Exposed Industries*, An Interagency Report Responding to a Request From Senators Bayh, Specter, Stabenow, McCaskill, and Brown (December 2, 2009, with corrections on February 23, 2010), http://go.usa.gov/T8pT (PDF, 1.8 MB).

[14] Christoph Böhringer, Edward J. Balistreri, and Thomas F. Rutherford, eds., "The Role of Border Carbon Adjustment in Unilateral Climate Policy: Results from EMF 29," *Energy Economics*, vol. 34, supp. 2 (December 2012), pp. S95–S250, http://tinyurl.com/c65mott.

leakage estimate dropped from 12 percent to less than 3 percent. The reason is that the portion of the 12 percent that represented leakage through the price of petroleum was reduced or eliminated.

In earlier studies, a number of analysts considered the effects of the Kyoto Protocol. That protocol was an international agreement that set emission-reduction targets for many industrialized countries at 5 percent below the 1990 levels, to be achieved between 2008 and 2012, but it did not specify how the targets were to be reached. The United States signed the protocol in 1998, agreeing to reduce GHG emissions by 7 percent from 1990 levels. However, the President never submitted the protocol to the Senate for ratification, and the United States has not attempted to meet its emission-reduction target. Nevertheless, a number of the analyses were conducted under the assumption that the United States would participate.[15]

According to a survey of studies that estimated leakage for Kyoto climate policies under that assumption, most estimates were between 5 percent and 20 percent of the projected emission reductions in Annex I countries.[16] Another study cited estimates in the literature ranging from 2 percent to 21 percent.[17] Still another survey cites other surveys finding estimates ranging from 2 percent to 23 percent.[18] That survey also points to a World Bank study that finds leakage of only 1 percent when high-income countries unilaterally cut their emissions in 2020 by 17 percent relative to their levels in 2005.[19]

Backward-Looking Estimates of Leakage

Other studies have looked at programs after they were implemented to determine how much leakage actually occurred, and another study analogously looked back at the effects of changes in energy prices (equivalent to increases in energy costs imposed by a carbon tax) on U.S. production and consumption and the implications for changes in trade and leakage.

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[15] See, for example, John P. Weyant, ed., *The Costs of the Kyoto Protocol: A Multi-Model Evaluation*, a special issue of *The Energy Journal* (Energy Economics Education Foundation, May 1999), http://tinyurl.com/bowde5c, which contains a number of such studies.

[16] J.P.M. Sijm and others, *Spillovers of Climate Policy: An Assessment of the Incidence of Carbon Leakage and Induced Technological Change Due to CO_2 Abatement Measures*, Report 500036-002 (Netherlands Research Programme on Climate Change, December 2004), p. 14, http://tinyurl.com/lh3f3pw (PDF, 1.29 MB).

[17] Jean-Marc Burniaux and Joaquim Oliveira Martins, *Carbon Emission Leakages: A General Equilibrium View*, Working Paper 242 (Organisation for Economic Co-operation and Development, May 2000), http://tinyurl.com/p5tzn4c (PDF, 548 KB).

[18] ZhongXiang Zhang, *Competitiveness and Leakage Concerns and Border Carbon Adjustments*, Working Papers in English 2012.080 (Fondazione Eni Enrico Mattei, 2012), p. 9, http://tinyurl.com/clzqb5z.

[19] Aaditya Mattoo and others, *Reconciling Climate Change and Trade Policy*, Policy Research Working Paper 5123 (World Bank, November 2009), http://tinyurl.com/d9arqqx.

Estimates of Leakage Shortly After Implementation. Even after a program has gone into effect, leakage cannot be observed directly; as is the case for projections of future leakage, current or past leakage must be estimated using models or statistical analysis. Projections of future leakage involve comparing trade at the time the projection is made with what trade is projected to be under the emission-reduction program. Estimates produced after the fact involve comparing trade under the program with what models or statistical analysis project that trade would have been without the program. Either way, known levels of trade must be compared with unknown levels that are projected using modeling or statistical analysis.

The EU implemented a relatively broad-based emission-reduction program known as the Emissions Trading Scheme, or EU-ETS, in 2005. The EU-ETS is a cap-and-trade program that in its pilot period (2005 through 2007) covered about half of the EU's CO_2 emissions and 40 percent of its GHG emissions. One study examined several aspects of the program during that period, including the rates of leakage for four industries—cement, iron and steel, oil refining, and aluminum.[20] (The study presented its own estimates and estimates from other studies.) Using statistical analysis, the study estimated net imports of the products as a function of domestic consumption and the price of emission allowances and found the allowance price not to be a significant determinant. Although projections and other evidence beforehand indicated that all four industries were likely to experience significant leakage, the study found no evidence of leakage from 2005 through 2007.

Another study examined the effects of the Climate Change Levy in the United Kingdom, which was begun in 2001.[21] That program imposes taxes on energy ranging from 6.1 percent on coal to 16.5 percent on natural gas. Some businesses are offered an 80 percent reduction in the tax if they join a climate change agreement, under which they must meet targets for energy use or CO_2 emissions. The study statistically analyzed differences in terms of output and other variables between firms that joined such agreements and those that did not. Using data through 2004, the study found no significant evidence of leakage.

[20] A. Denny Ellerman, Frank J. Convery, and Christian de Perthuis, *Pricing Carbon: The European Union Emissions Trading Scheme* (Cambridge University Press, 2010), http://tinyurl.com/cmhj55v.

[21] Ralf Martin, Laure B. de Preux, and Ulrich J. Wagner, *The Impacts of the Climate Change Levy on Manufacturing: Evidence from Microdata*, Working Paper 17446 (National Bureau of Economic Research, September 2011), www.nber.org/papers/w17446.

Still another study examined the responsiveness of U.S. production and consumption of manufactured goods in the short term to changes in energy prices in recent years.[22] That approach is analogous to looking back on the effects of a broad-based emission-reduction program because such programs work by effectively making the use of carbon-based energy more expensive. The study used statistical analysis to determine the extent to which production and consumption of the products of more than 400 manufacturing industries had been affected in recent years by changes in energy prices. It estimated that a change in energy prices that was the equivalent of imposing a tax of $15 per ton on CO_2 caused average declines of 1.4 percent in production and 0.4 percent in consumption over the first few years. Those numbers imply that 1 percent of production would shift to other countries in the first few years, thereby producing leakage. The magnitude of the leakage cannot be determined from the results of the study. Nevertheless, unlike the studies of the EU-ETS and the Climate Change Levy, this study found evidence of increases in energy costs (such as would result from a carbon tax) causing displacement of U.S. production by foreign production in the short term.

Estimates of Leakage Over the Short and Long Term. The results of the study of the effects of higher energy prices on production and consumption indicate that leakage would probably occur in the early years of an emission-reduction program, and the results of the other two backward-looking studies constitute evidence that leakage at that point would probably be small, perhaps so small as to be difficult to detect. The latter results do not, however, indicate the likely magnitude of leakage in later years.

As noted in the cautions about using leakage estimates, leakage in the initial years after a program is implemented is likely to be much lower than in later years. Even if and when the increase in costs resulting from an emission-reduction program is sufficient to make production less expensive in another country for a given firm, that firm is not likely to move its production until it is convinced the policy will remain in place—that is, that policymakers will neither eliminate the program nor decrease the magnitude of the required reduction in emissions when they face complaints from firms and their employees who lose jobs. In addition, a firm would want to be assured that a similar emission-reduction program would not be implemented in the country to which it intended to move production. That firm also is unlikely to move production until its plant and equipment have largely depreciated. Even if competition from the other country drove down the domestic price to a point that the firm was losing money, that firm would continue to produce as long as its plant and equipment was still functional and the price was higher than the firm's marginal cost (its total cost minus the cost of the plant and equipment, which is a sunk, or unrecoverable, cost). Moreover, certain features of the way that emission allowances were distributed in

[22] Joseph E. Aldy and William A. Pizer, *The Competitiveness Impacts of Climate Change Mitigation Policies*, Working Paper 17705 (National Bureau of Economic Research, December 2011), www.nber.org/papers/w17705.

the pilot period of the EU-ETS could be expected to further delay the movement of production abroad. The resulting low levels of leakage in the early years of a program could be difficult to detect with only a few years of data, but the larger leakage to be expected later would be more easily detected in many years of data.

Estimates of Leakage Rates Under More Narrowly Focused Programs

The leakage estimates presented above are for economywide emission-reduction programs such as a carbon tax or a cap-and-trade program applied to all or almost all emissions. Leakage could be different in programs that are more narrowly focused. For example, rates of leakage are likely to be lower for production standards targeting industries with little foreign competition than for such standards targeting industries with substantial foreign competition. Similarly, under a cap-and-trade program that applied only to electrical generating plants, the array of industries facing significant increases in their costs and consequent declines in their competitiveness would be different from that for an economywide cap-and-trade program. Given the differences among industries in the amount of foreign competition they face, the rate of leakage for a cap-and-trade program applied to electrical generating plants would therefore probably be different from that of an economywide program.