BACKGROUNDER

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Climate Policy, International Trade, and Emissions Leakage

Juha Siikamäki, Clayton Munnings, Jeffrey Ferris, and Daniel Morris

1616 P St. NW
Washington, DC 20036
202-328-5000 www.rff.org

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Climate Policy, International Trade, and Emissions Leakage

Juha Siikamäki, Clayton Munnings, Jeffrey Ferris, and Daniel Morris *

I. Introduction

Emissions leakage occurs when sources outside the scope of a greenhouse gas (GHG) emissions reduction system increase emissions as a result of that system. Leakage can significantly undermine initiatives to reduce GHG emissions. Leakage of carbon dioxide (CO_2) is particularly relevant because CO_2 is a global stock pollutant. That is, the geographic location or the economic sector of the emissions source is not important in terms of environmental impact; a reduction from one source is comparable to that from another source in an entirely different geographic region.

No national or regional emissions reduction system can entirely avoid leakage because production tends to shift from regulated regions and sectors, where compliance costs are high, to unregulated regions and sectors, where compliance costs can be avoided. Without a global cap or tax on GHG emissions, leakage will remain an important consideration for GHG reduction policies at any scale.

The purpose of this backgrounder is to highlight existing research on leakage and, by doing so, help evaluate the data and methods required for such assessments. We begin by briefly summarizing common research methodologies and concepts in leakage assessments. Thereafter, we quickly explain different climate policies assessed in leakage research. Following that, we summarize the key findings of the studies examined. The backgrounder concludes with a discussion of the potential limitations of leakage studies.

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*Siikamäki, Munnings, and Morris, Resources for the Future, juha@rff.org; Ferris, University of Maryland.

This backgrounder is one in a series prepared for the project "Planning for the Ex Post Analysis of U.S. Climate Policy" to inform discussions and assessments of U.S. climate policy. The backgrounders summarize research on the following topics: (i) competitiveness impacts of climate policy; (ii) climate policy, international trade, and emissions leakage; (iii) Kyoto flexibility mechanisms: the Clean Development Mechanism and joint implementation; (iv) land use, land-use change, and forestry; (v) EU Emissions Trading System, and (vi) the U.S. Environmental Protection Agency's Acid Rain Program. Taken together, these backgrounders summarize research on several key aspects of climate policy. In addition to helping inform discussions and assessments of climate policy, the backgrounders are intended to provide informative overviews of each topic to anybody interested in conducting or better understanding climate policy assessment, including researchers, students, and experts in academia, government, nongovernmental organizations, and industry. Funding for this project has been provided by the Alfred P. Sloan Foundation.

II. Research on Emissions Leakage

A. Central Research Methodologies

To estimate the magnitude of leakage, researchers often use *partial equilibrium* (PE) or *general equilibrium* (GE) computational modeling. PE models focus on a single market subset and are often used to estimate emissions leakage at the sector level. GE models mimic the behavior of entire economies and therefore are composed of many sectors and interacting markets. PE models are best suited for modeling economic relationships that are primarily contained within the modeled sector or part of the economy, whereas GE models help better capture broader economic impacts, including interrelationships among different economic sectors or effects in different geographic regions or countries. Both PE and GE models require the development of stylized models of economies, which include various assumptions about market structure, substitution patterns, and production and transportation costs.

Trade-offs are inherent in choosing between PE and GE analyses. Although PE models may be well-suited to a particular sector, they do not capture impacts outside of the markets examined in the analysis. Although GE models better capture interactions within and among markets and economies, they are more complex and may require the use of more aggregated data; this can mask the true impact of a GHG reduction system on a particular sector.

B. Essential Terminology

Researchers usually estimate a *leakage rate* as the portion of GHG abatement in a region with regulated emissions that is offset by an increase of emissions in unregulated regions. Relocation of production from regulated to unregulated regions is an important pathway for leakage because the carbon content per unit production in unregulated regions is higher than in regulated regions, so any production shifts to unregulated regions lead to greater emissions. Two additional leakage pathways are price and investment pathways. The price pathway is associated with reduced demand for fossil fuels because of GHG regulations; this puts downward pressure on world fossil fuel prices, increasing their demand and consequent emissions. The investment pathway relates to the decrease in returns on capital due to GHG regulation, which may shift investment overseas. Because the carbon content of unit production is typically higher in the unregulated regions, this shift in investment can also increase emissions (Zhou et al. 2010).

Certain sectors are more likely to contribute to emissions leakage than others, particularly sectors that emit large amounts compared to their output and are highly exposed to international competition. These sectors, which are usually the focus of PE analyses, are often denoted *emissions-intensive, energy-intensive,* and/or *trade-exposed.*

In addition, the market structure in which firms compete may influence leakage rates. Competitive markets are associated with low *pass-through rates*—the share of an increase in marginal cost that is passed on in product prices—while oligopoly or monopoly markets are associated with high pass-through rates. Firms that can pass-through rates are able to recoup some, or all, cost increases due to carbon price by increasing product prices. Thus, monopolistic markets tend to be associated with lower leakage rates.

Border tax adjustments (BTAs) offer one potential policy option for minimizing carbon emissions leakage. The simplest BTA policies are import taxes and export rebates. Taxes placed on imports penalize emissions associated with trade from countries without a GHG emissions reduction system, whereas rebates reward exporters located in countries with a GHG emissions reduction system by returning the value of emissions embodied in the domestic product (Fischer and Fox).[1]

C. Policies Addressed

A relatively large body of research has emerged on the effects of leakage in the context of existing GHG policies—the Kyoto Protocol, the E.U. Emissions Trading System (E.U. ETS), and the Regional Greenhouse Gas Initiative (RGGI)—and impending GHG policies, such as the European Union's energy–climate package, California's cap-and-trade system, and federal-level GHG policy proposals in the United States.

The Kyoto Protocol, an international agreement linked to the U.N. Framework Convention on Climate Change, was adopted in Kyoto in 1997 and entered into force in 2005. It set targets for industrialized countries to reduce GHG emissions in 2008-2012 by 4.2 percent relative to the base year, which in most cases is 1990 (Olivier et al. 2011). The United States is the only industrialized country that did not ratify the Kyoto Protocol.

The E.U. ETS, which has been in operation since 2005, affects all major energy and industrial installations in the European Union.[2] As the largest GHG trading system in the world,

[1] Fischer and Fox (2009). Two additional BTAs include *full border adjustment*, which combines import taxes and export rebates, and *output-based rebating*.

[2] All facilities that produce heat in excess of 20 megawatts per year are included in the E.U. ETS.

covering 12,000 installations across the European Union and leveraging billions of Euros' worth of investments in carbon mitigation, the E.U. ETS has recently been expanded to cover emissions from air transportation.[3] In 2008, the European Union approved the energy–climate package that covers and sets targets for the ETS and sectors not included in the system. This package calls for the European Union to reduce GHG emissions to 20 percent below 1990 levels by 2020, improve energy efficiency by 20 percent, and increase the share of renewables in the E.U. energy mix to 20 percent. For ETS sectors, the package calls for an extension of coverage, full auctioning of allowances by 2027, and a cap declining linearly to 20 percent below 1990 levels by 2020. For non-ETS sectors, reduction targets have been determined for each member country based on its gross domestic product per capita (Europa 2008).

In the United States, several congressional proposals have emerged for comprehensive federal GHG policy. Although none of the proposals succeeded, these federal policy options have been the subject of considerable research. Additionally, some states have moved forward with their own GHG policies. For example, 10 states in the Northeast and Midatlantic have formed the RGGI to regulate GHG emissions in their region. In California, the Global Warming Solutions Act, also known as A.B. 32, includes a broad-based approach to limit GHG emissions. It covers over 80 percent of all emissions and includes a cap-and-trade program with offset provisions. These state and regional policies also have been the subject of research, which we discuss next.

D. Key Findings

Results from research on leakage suggest a wide range of leakage under different GHG emissions reduction systems. As expected, the estimated leakage rates are lowest under the Kyoto Protocol, which is a global policy with the greatest coverage of potential sources. Moreover, leakage rates are higher under regional programs—including the E.U. ETS, RGGI, and California's A.B. 32—and in energy-intensive sectors such as aluminum, steel, and cement production. We summarize the findings below.

1. Kyoto Protocol

Leakage under the Kyoto Protocol has been estimated on both regional and sectoral levels using primarily GE models, with some PE analysis (see Table 1). The selected studies

[3] These changes take effect in 2012.

exhibit a variety of assumptions regarding country participation and trade agreements. For each of the following studies, the authors assume that each country participating in the Kyoto Protocol imposes a unique carbon tax to satisfy its obligation. The exception is Demailly and Quirion (2006b), where the authors assume a universal €15/ton carbon price in all Kyoto-participating countries and regions.

Assuming U.S. participation in the Kyoto Protocol, Paltsev (2001) estimates a global leakage rate of 10.5 percent[4] and the following regional-level leakage rates: 16.3 percent for Europe, 13.3 percent for Japan, 12.9 percent for Canada, 5.5 percent for the United States, and 2.8 percent for the former Soviet Union. Furthermore, the author finds the highest sector-level leakage rates within the iron and steel (28.2 percent), mining (28.0 percent), and nonferrous metal (26.3 percent) industries. Assuming minor reductions from the United States,[5] Kuik and Gerlagh (2003) estimate a global leakage rate of approximately 11 percent without—and 15 percent with—trade liberalization protocols agreed to under the Uruguay Round of multilateral trade negotiations in 1994. These negotiations effectively reduced import tariffs.

Assuming no U.S. participation in Kyoto, Babiker and Rutherford (2005) estimate a global leakage rate of 30 percent. According to the authors, this value differs from comparable studies that assumed U.S. participation because the United States is likely to be a large source of leakage, possibly accounting for up to one-third of estimated global leakage. In addition, the authors assess the impact of a suite of BTA policies on leakage rates, finding a low value of 19 percent if energy-intensive sectors are exempt from a carbon price and a high value of 38 percent if countries without a carbon price impose voluntary export restraints. The authors conclude that the latter BTA policy—along with import taxes and export rebates—are ineffective at minimizing leakage. Finally, the authors consider the impact on leakage rates of two flexibility mechanisms: (a) allowing trading among all Kyoto regions and (b) allowing such trading with the inclusion hot-air credits, which are allowances allocated in excess of a country's baseline

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[4] In the author's central scenario, the reduction in GHGs from Kyoto-participating countries is estimated to induce an increase in emissions from developing countries of 380 million tonnes (Mt). Specifically, the following Kyoto-participating countries induce the associated portion of these leaked emissions: 29.4 percent for the United States, 41.4 percent for Europe, 7.1 percent for Canada, and 16.6 percent for Japan. Of the 380 Mt of emissions leaked to non-Kyoto countries, China accounts for 30 percent, the Middle East for 24 percent, the rest of Asia for 13 percent, and the rest of the world region for 25 percent. These figures represent gross, not relative, levels of leakage.

[5] At the time the Kuik and Gerlah (2003) paper was written, the United States had withdrawn from Kyoto and, instead, pledged a less-stringent goal of reducing emissions intensity by 18 percent relative to 2012 projections.

emissions. Allowing trade only and trade with hot-air credits reduces the estimated leakage rate from 30 percent to 17 percent and 9 percent, respectively. Overall, the lowest leakage rate (7 percent) results from allowing trade with hot air-credits and exempting energy-intensive sectors from a carbon price.[6]

Assuming no U.S. participation in Kyoto and using a PE model, Peterson and Schleich (2007) estimate a range of leakage rates by considering different values for the elasticity of substitution and BTA policies. In addition, the authors explicitly include domestic trade and transportation margins.[7] The authors assume that each Annex B country will fulfill its Kyoto obligations with a single carbon tax. They also assume that hot-air credits will not be traded. Given these assumptions, the authors find that the lowest leakage rate estimate (21 percent) results from a BTA policy that covers ETS sectors and certain non-ETS sectors and an assumption that elasticities of substitution are low, whereas the highest leakage rate estimates (28 percent) result from a BTA policy that covers ETS sectors only and an assumption that elasticities of substitution are high.[8] Overall, the authors conclude that BTA policies do not significantly reduce leakage.

Assuming no U.S. participation in Kyoto and a carbon price of €15, Demailly and Quirion (2006b) assess the effectiveness of two BTA policies on reducing leakage from the cement sector.[9] The authors assess the following BTA policies: "complete BTA," which exempts cement exports originating in Annex B countries from a carbon price and taxes imports to Annex B countries from non-Annex B countries according to the emissions intensity of cement production in the country of origin, and a "WTO BTA," which rebates cement exports originating in Annex B countries, according to the best available technology in Annex B

[6] In this case, flexible wages are assumed. Sticky wages actually lead to lower estimated leakage rates (on the order of 1–4 percent lower), but the authors did not assess the case of sticky wages under trading with hot-air credits, which might result in a leakage rate estimate lower than 7 percent.

[7] Including domestic and trade margins captures the substantial impact that the transportation, wholesaling, and retailing industries have on transaction prices between domestic producers and consumers. For more information, see Peterson and Lee (2005).

[8] The authors did not directly calculate a leakage rate. These values are found by dividing the "global emissions reductions" rows in their Table 6 by the gross "leakage rates" found in those tables.

[9] The authors link their CEMSIM model with the GEO model, the latter of which accounts for transportation costs associated with the cement trade and replaces standard Armington elasticities for the elasticity of trade with elasticities that are, the authors argue, more appropriate for the cement industry (Demailly and Quirion 2005). Specifically, the assumption of imperfect substitution among goods produced in different places (Armington elasticity substitution) is dropped because cement is a homogeneous product.

countries, and taxes imports to Annex B countries from non-Annex B countries equivalently.[10] The authors estimate the following leakage rates in 2010: 25 percent for a carbon price without a BTA policy, –6 percent for a complete BTA policy,[11] and 4 percent for a WTO BTA policy.

Table 1. Research on Leakage under the Kyoto Protocol

Study	Region	Industry focus	Key data	Model	Estimated leakage
Paltsev (2001)	Global	Economywide	GTAP-EG	GE	10.5%
Kuik and Gerlagh (2003)	Global	Economywide	GTAP-4E, DOE	GE	11%
Babiker and Rutherford (2005)	Global	Economywide	GTAP, OECD-EIA, and DOE	GE	7% to 38% (varies by policy)
Peterson and Schleich (2007)	European Union	Economywide	GTAP-E	GE	21% to 28%
Demailly and Quirion (2006b)	Global	Cement	CEMSIM, GEO, POLES	PE	–6% to 25% (varies by BTA policy)

2. The European Union Emissions Trading System

A number of PE analyses estimate sector-level leakage resulting from the E.U. ETS, especially from the cement and iron industries (see Table 2). Demailly and Quirion (2008b)

10 The best available technology is assumed to be the dry rotary kiln with preheater and precalciner fueled with natural gas. The latter policy is named WTO BTA because, compared to the complete BTA, this one is more likely to be upheld by the World Trade Organization.

11 A complete BTA policy improves the position of Annex B producers because costs to similar firms in non-Annex B countries increase (as these firms are generally more carbon intensive than those in Annex B). Partly because of this advantage, Annex B exports to non-Annex B countries temporarily increase, somewhat replacing the consumption of the more carbon-intensive cement originating in the non-Annex B countries. To an extent, this replacement lowers the dirtier production in non-Annex B countries so that this BTA policy acts to reduce global emissions by 6 percent.

examine the effectiveness of five allowance allocation approaches[12] at reducing leakage in three sectors covered by the E.U. ETS (electricity, steel, and cement) and aluminum, which is not a covered sector but is influenced greatly by the E.U. ETS because of its large electricity requirements. Together, these four sectors account for 75% of the emissions covered by the E.U. ETS. For a 15 percent reduction from 2005 emissions levels by 2015,[13] the authors find an overall leakage rate between –2 and 8 percent, the former number resulting from a full auction of allowances with BTAs (AU-BTA) and the latter from grandfathering or full auctioning (GF/AU). For the same level of emissions reductions mentioned above, the authors estimate the following approximate leakage rates for AU-BTA and GF/AU, respectively: –10 to 20 percent for cement, 0 to 50 percent for steel, and very low negative leakage rates (exceeding –30 percent) to positive leakage rates (30 percent) for aluminum.

Ponssard and Walker (2008) estimate leakage rates for the cement industry assuming a pure auction of E.U. allowances, carbon prices of €20and €50, and an oligopolistic cement market. The authors' lowest leakage rate (63 percent) results from a carbon price of €20 and high elasticity of demand for cement, whereas the author's highest leakage rate (73 percent) results from a carbon price of €50 and low elasticity of demand for cement. In contrast, Demailly and Quirion (2006a) estimate lower leakage rates for the cement industry under two allowance allocation approaches: grandfathering and output-based allocation.[14] Furthermore, the authors assume (a) that non-E.U. countries have not enacted GHG reduction systems and (b) a carbon price of €20. Given these assumptions, during the 2008–2012 period, the authors estimate an average leakage rate of around 50 percent under a grandfathering allocation approach and 9 percent under an output-based allocation approach.

Ritz (2009) provides simple formulas to estimate leakage rates for the steel industry under varying assumptions for the availability of efficiency improvements. The author finds the lowest leakage rate under high (50 percent) efficiency gains and the highest leakage rate for no

[12] The allowance allocation approaches considered were: output-based allocation (where firms receive free allowances proportional to current output); grandfathering (where all allowances are distributed freely without taking into account new information); auctioning (where all allowances are auctioned); auctioning with BTAs (where all allowances are auctioned, but exporters of E.U. goods would get refunded for their CO_2 charge); and output-based allocation in the cement and steel sectors and auctioning in the electricity sector.

[13] The authors also assess leakage rates under a wider range (0 to 30 percent) of emissions reductions.

[14] Under the grandfathering approach, the authors allocate 90 percent worth of firms' 2004 emissions for free. Under the output-based approach, the authors allocate 90 percent worth of firms' 2004 emissions per tonne of cement.

efficiency improvements. For the iron and steel industry combined, Demailly and Quirion (2008a) perform a rigorous sensitivity analysis by varying five key variables—marginal abatement cost curves, price elasticity of demand for iron and steel, price elasticity of imports and exports of iron and steel, domestic and export pass-through rates, and assumptions surrounding the allowance allocation updating approach—to estimate a range of leakage rates between 0.5 and 25 percent, with a mean of 6 percent. Furthermore, the authors find the leakage rate to be very likely[15] less than 15 percent.

Considering the E.U. Energy–Climate Directive, Bernard and Vielle (2009) estimate a leakage rate of around 7 percent for the European Union in 2020 for ETS and non-ETS sectors combined. In addition, the authors estimate a net leakage rate of 0.9 percent for the European Union in 2020 for all sectors combined except the fossil fuels industry. Also, whereas most researchers calculate leakage rates by comparing emissions increases in regions without GHG regulation to abatement within the GHG regulation region, Bernard and Vielle (2009) offer the concept of a *net leakage rate*, which defines leakage more narrowly, based on the production pathway. Specifically, only emissions that are in excess of what would have occurred if production remained in the regulated countries are counted as leakage. Thus, estimates of net leakage rates are generally lower than those of leakage rates.

[15] The authors define "very likely" as greater than 90 percent certainty.

Table 2. Research on Leakage under European Union Policies

Study	Region	Industry focus	Key data	Model	Estimated leakage
Demailly and Quirion (2008b)	European Union	Cement, aluminum, electricity, and steel	CASE, PRIMES	PE	For all sectors: –2% to 8% (varies by BTA policy and sectorally)
Demailly and Quirion (2006a)	European Union	Cement	CEMSIM-GEO, POLES, OECD	PE	9% to 50% [16] (varies by BTA policy)
Ponssard and Walker (2008)	European Union	Cement	Industry sources, Eurostat	PE	56% to 73%
Demailly and Quirion (2008a)	European Union	Steel and iron	IEA, ECSC, Eurostat	PE	0.5% to 25%
Ritz (2009)	European Union	Steel	IEA	Analytical	9% to 75%
Bernard and Vielle (2009)	European Union	All ETS and non-ETS sectors	GEMINI-E3 Model, IEA, EIA	GE	7%

Notes: ECSC, European Coal and Steel Community.

3. United States Greenhouse Gas Policies

Two economywide studies employing GE analyses—Ho et al. (2008) and Fischer and Fox (2009)—estimate leakage rates resulting from a national U.S. carbon price (see Table 3). Assuming an economy-wide carbon price of $10 and no BTAs, Ho et. al (2008) estimate an overall leakage rate of 25 percent and the following sector-level leakage rates: 52 percent for chemicals, 46 percent for nonmetallic minerals, and 41 percent for primary metals. Fischer and Fox (2009) quantify leakage on a sector-by-sector basis, under a variety of BTA policies and a

[16] Average values for the 2008–2012 period.

carbon price of $14 on certain emissions-intensive sectors. These authors estimate the following leakage rates for each sector: 64 percent for refined petroleum products; 60 percent for iron and steel; 39 percent for nonmetallic minerals; 20 percent for chemicals; 11 percent for paper, pulp, and print; and 8 percent for electricity.

Studies addressing RGGI and California's A.B. 32 use PE analyses and focus on the electricity sector for two reasons. First, the electricity sector is an important part of each cap-and-trade system; for example, RGGI's system covers the electricity sector exclusively. Second, under a state or regional program, the electricity sector is particularly likely to leak emissions because the highly interconnected U.S. transmission system allows producers the flexibility to easily offset regional reductions in carbon emissions with increased carbon generation in unregulated states.

For California's cap-and-trade program under A.B. 32, Palmer et al. (2009) estimate two leakage rates for the state's electricity sector: one under full auctioning of allowances (26 percent) and another under free allocations to local distribution companies based on their load (45 percent). The authors state that if California were to ignore emissions from imported electricity, a policy that is not consistent with A.B. 32 and is highly unlikely to occur, emissions leakage would approach 100 percent. Three studies have estimated leakage rates from RGGI ex ante. First, ICF conducted a study for RGGI Inc. to estimate leakage rates for RGGI. The study uses the Integrated Planning Model (IPM) to predict RGGI carbon prices—between $2 and $3 dollars throughout 2012—and offset purchases (ICF Consulting 2006a, 2006b). Given these projections, the study estimates a leakage rate of 27 percent through 2015 (RGGI Inc. 2007). Earlier estimates of leakage rates, under lower price scenarios, were lower: 18 percent (RGGI Inc. Emissions Leakage Multi-State Staff Working Group 2007). Note that these estimates include offsets.

Second, commenting on the ICF study, Kindle et al. (2011) observe that if carbon offsets are excluded, the leakage rate reaches nearly 50 percent. Kindle et al. (2011) also discuss Shawhan et al. (2010)—a study that estimates a much higher leakage rate—stating that, for an RGGI carbon price of $3.87, Shawhan et al. estimate an 82 percent leakage rate. Third, Chen (2009) estimates much higher leakage rates for RGGI. Under a range of carbon prices from $1 to $10, the author finds leakage rates of at least 85 to 90 percent.

In an ex post study of RGGI, Kindle et al. (2011) conduct regression analyses to test for an increase of CO_2 emissions (leakage) from Pennsylvania induced by New York's compliance with RGGI. To do so, the authors statistically test two hypotheses: (a) RGGI prices are a significant explanatory variable for power flow from Pennsylvania to New York and (b) RGGI prices are a significant explanatory variable for CO_2 emissions in Pennsylvania. The results of the authors' regressions reject both of these hypotheses. The authors conclude that RGGI allowance prices had not been high enough to induce leakage.

4. Other United States Policies

Goulder et al. (2009) estimate leakage rates from the Pavley regulations, which impose limits of GHG emissions per mile for light-duty automobiles and have been adopted by 14 states. Leakage from these regulations results from two pathways. First, interactions between corporate average fuel economy (CAFE) standards and the Pavley regulations allow certain automobile manufacturers to increase the sale of cars with lower fuel economy in states not subject to Pavley standards; the resulting emissions increase represents emissions leakage caused by regulatory overlap.[17] Second, the Pavley regulations reduce the rate at which used cars are scrapped, leading to higher emissions (leakage) as these less fuel-efficient cars remain on the road for longer than they otherwise would have. In their central scenario, the authors estimate a leakage rate of 96 percent in the first year of the Pavley regulations, which declines to 80 percent by 2020. Then the authors perform a sensitivity analysis by varying key parameters, estimating no leakage rates below 59 percent.

Murray et al. (2004) focus on land-based emissions by estimating regional leakage rates for four hypothetical forest policies to reduce carbon emissions in the United States: forest set-asides, avoided deforestation, afforestation, and a national policy that rewards afforestation and penalizes deforestation via a carbon price. For these programs, leakage may result from the increased harvest in, or conversion to agriculture, of nonregulated forests. Overall, the authors estimate a range of leakage rates between 7 and 92 percent. The authors find the lowest leakage rate for the carbon price mechanism and the highest leakage rate resulting from reduced forest loss in the Great Lake States.

[17] From Goulder et al. (2009, 36): "Since CO_2 emissions and gasoline use are nearly proportional, the Pavley limits effectively raise the fuel economy requirement for manufacturers in the states adopting such limits. Consider an auto manufacturer that, prior to the imposition of the Pavley limits, was just meeting the U.S. CAFE standard. Now it must meet the (tougher) Pavley requirement through its sales of cars registered in the adopting states. In meeting the tougher Pavley requirements, its overall U.S. average fuel economy now exceeds the national requirement: the national constraint no longer binds. This means that the manufacturer is now able to change the composition of its sales outside of the Pavley states; specifically, it can shift its sales toward larger cars with lower fuel-economy."

Table 3. Research on Leakage under United States Policies

Study	Region	Industry focus	Key data	Model	Estimated leakage
Fisher and Fox (2009)	United States	Economywide, sector specific	GTAP-EG	GE	8% to 64% (varies sectorally)
Ho et al. (2008)	United States	Economywide	MECS, Annual Energy Review, USDA	GE	25%
Palmer et al. (2009)	California (A.B. 32)	Electricity	EIA	PE	26% to 100%
ICF Consulting (2006a, 2006b), RGGI Inc. Emissions Leakage Multi-State Staff Working Group (2007)	RGGI states	Electricity	IPM	PE	27% to 50%
Chen (2009)	RGGI states	Electricity	Platts database, generation data	PE	85% to 90%
Shawhan et al. (2010)	RGGI states	Electricity	Cornell–RPI model	PE	82%
Kindle et al. (2011)	New York and Pennsylvania	Electricity	NYISO, previous studies	Regression	No significant leakage found
Goulder et al. (2009)	14 U.S. states (Pavley regulations)	Automotive	Industry, EIA, World Bank, USDOT	PE	59% to 96% (varies over time)
Murray et al. (2004)	United States	Forestry	FASOM	PE	7% to 92% (varies regionally and by policy)

Notes: USDOT, U.S. Department of Transportation; MECS, Manufacturing Energy Consumption Survey; NYISO, New York State Independent System Operator; RPI, Rensselaer Polytechnic Institute; USDA, U.S. Department of Agriculture.

III. Available Data

The majority of GE analyses rely on the Global Trade Analysis Project (GTAP) database (see the Backgrounder on GTAP), a trade analysis research network coordinated by the Department of Agricultural Economics at Purdue University. Sometimes authors supplement GTAP data with data from the International Energy Agency (IEA), OECD, U.S. Energy Information Administration (EIA), and the U.S. Department of Energy (DOE).

For PE analyses, authors typically rely on a mixture of public and private data sources. In their analyses of the E.U. ETS, Demailly and Quirion (2008a) and Ponssard and Walker (2008) relied heavily on private industry data sources. Conversely, Palmer et al. (2009) relied entirely on public data sources.

IV. Research Limitations

As with any empirical research, research on leakage is constrained both by data and by methods. For example, trade-offs are inherent to the choice between GE and PE models, and both types of models necessarily involve simplification and must rely on assumptions and parameters from elsewhere. Regarding data limitations, the lack of comprehensive and sufficiently disaggregated data can limit the feasible scope and resolution of analyses.

One of the challenges in using GE models to estimate leakage is that parameter estimates underlying the model results may not be accurate, especially over the long term. Results are especially sensitive to energy supply elasticity and the elasticity of substitution between the products of different countries (which authors often refer to as Armington elasticities).[18] For example, Paltsev (2001) finds that varying the assumptions of energy supply elasticities and Armington elasticities yields a range of estimated leakage rates of 4.7 to 14.7 percent and 6.9 to 15.4 percent, respectively. Uncertainty in these parameter estimates translates into uncertainty in estimates for global leakage (Babiker and Rutherford 2005).

Moreover, this literature relies almost exclusively on the GTAP database. This makes sense because GTAP is the only publicly available database that has country and international

[18] Armington elasticities are based on the assumption that internationally traded products are differentiated by country of origin. The replacement of traditional trade elasticities with Armington elasticities will generally result in a less sensitive response in changes in trade flows from a carbon price. For further detail, see Armington (1969).

data on sector-level input–output matrices and global supply elasticities.[19] This is a major advantage that enables replicability of the studies and helps cross-study and cross-policy comparisons. However, GTAP, though comprehensive, is not specifically intended to model global climate policy (Fisher and Fox 2009). Moreover, if GTAP is subject to specific limitations, the broad reliance on it could produce systemic bias in the literature. For example, GTAP uses a high level of aggregation of sectors, which prevents researchers from examining the level of disaggregation necessary to more fully model the dynamic flows of global leakage. This could lead to lower estimates of emissions leakage (Morgenstern et al. 2007).

Some studies, especially those focused on specific sectors, draw from unique access to industry-specific databases. Besides hindering the replicability of studies, the data are not necessarily industrywide, and even for a single industry, the lack of overlap in underlying private and public data can lead to uncertainties in the results. Second, although researchers may have access to detailed industry profiles for specific countries, such data are generally not available at a global level.

Demailly and Quirion (2008a) identify pass-through rates as an important determinant of leakage rates that researchers rarely address explicitly. Furthermore, the possible values for this range are not well bound; estimates range from 25 to 100 percent. Assigning a broad range of pass-through rate values found in the existing literature, the authors find a range of possible leakage rates of 3 to 7 percent.

Uncertainties regarding the implementation and specifics of yet-to-be-implemented GHG policies impose additional levels of uncertainty. Although they are necessarily present in any ex ante assessment, they need to be taken into account when making cross-study and cross-policy comparisons and otherwise generalizing the study results.

[19] Note that developing nations generally have less accurate parameter estimates for industry supply functions than do developed nations. Generally, the reliability and availability of other data may also vary by country and by region and between the developing and developed world.

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