Challenges in the Measurement of Leakage Risk

By Meredith Fowlie and Mar Reguant*

With the launch of China's Emissions Trading Scheme in 2018, more than a quarter of global greenhouse gas (GHG) emissions will be subject to some form of carbon pricing (World Bank, Ecofys and Vivid Economics, 2017). This is an important milestone. But one that still leaves the majority of global GHG emissions unpriced.

The global nature of climate change creates challenges for a policy regime that covers only a subset of the sources contributing to the problem. If these incomplete policies induce a reallocation of economic activity from regulated to unregulated jurisdictions, the associated "leakage" of GHG emissions can offset emissions reductions and undermine cost effectiveness. Thus, concerns about emissions leakage loom large in debates about regional climate change policy.

Correctly identifying the kinds of economic activities most at risk of carbon leakage is a critical first step in the design of effective risk mitigation. In this short paper, a simple formulation of emissions leakage provides a conceptual framework for leakage risk assessment in theory and practice. We briefly summarize current approaches to assessing leakage risk and highlight a sizable gap between academic research and real-world policy implementation. An emerging research agenda that aims to close this gap is discussed.

I. Carbon Leakage in Theory

From the perspective of a country introducing unilateral GHG emissions regulation, emissions leakage can be defined as the increase in foreign emissions that is caused by the introduction of the domestic regulation:

$$L_{it} = \Delta_\tau E^f_{it}, \tag{1}$$

where E^f_{it} refers to GHG emissions for a foreign industry i at time t, and Δ_τ represents the change induced by the domestic regulation denoted by τ.

Equation (1) can encapsulate two related but conceptually distinct leakage channels. First, policy-induced increases in operating costs can cause industrial production (and associated emissions) to move to jurisdictions outside the reach of the regulation via trade flows (i.e. the trade channel). Second, if emissions regulations in a large open economy reduces demand for carbon-intensive inputs (e.g. fossil fuels), global input prices will fall and stimulate demand for these inputs in unregulated regions.[1]

With the proliferation of regional climate change policy initiatives, there is a burgeoning literature assessing the potential for leakage risk across a range of Emissions Intensive and Trade Exposed (EITE) industries. Some research looks exclusively at the trade channel, often focusing on a single industry in order to capture structural determinants of policy impacts in detail. An alternative approach uses multi-sector and multi-region CGE models which capture complex global trade linkages and energy flows. Importantly, CGE modeling can accommodate both partial and general equilibrium impacts. However, the complexity of these models can confound intuitive interpretation and complicate the link between theory and empirics.

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[1] Although much of the policy debate has focused on the first (trade) channel, economists have underscored the theoretical importance of the fossil fuel market channel. See, for example, Böhringer, Lange and Rutherford (2014).

Given the practical difficulties in empirically implementing Equation (1), it is not uncommon to further simplify the expression. Invoking some additional assumptions, emissions leakage can be expressed as:

$$\tilde{L}_{it} = \overline{e}^f_{it} q^f_{it} \eta_{it}. \tag{2}$$

One simplifying assumption is that policy-induced emissions changes are proportional to output changes, scaled by the emissions rate $\overline{e}^f_{it}$. A second assumption is that the policy-induced change in foreign output can be represented as the product of the elasticity of foreign output with respect to domestic policy costs, η_{it}, and the level of foreign output, q^f_{it}.

II. Carbon Leakage Risk Assessment in Practice

Absent a globally coordinated effort to regulate GHG emissions, several jurisdictions have implemented (or are planning to implement) unilateral GHG regulations. In some cases, EITE industries have been exempted on account of concerns about leakage risk. In other cases, policies have incorporated leakage mitigation in the form of output-based subsidies targeted at EITE industries.

Given the large number of sectors covered by these programs, and the political nature of determining which industries are eligible for special treatment due to leakage risk, there is a pragmatic need for a transparent and politically durable approach to risk assessment that can be applied consistently across industries. Equation (2) provides a relatively simple jumping off point, highlighting the relationship between emissions leakage, emissions intensities, and trade elasticities. But even this highly stylized benchmark can be difficult to calibrate in practice. Instead, policymakers have focused on two related metrics: *domestic emissions (or energy) intensity* (EI) and *trade exposure* (TE).[2]

Policy makers acknowledge the *ad hoc* nature of current approaches to leakage risk assessment and mitigation. But it has been very difficult to more directly connect the existing academic literature to policy implementation. Industry-specific studies offer precise guidance with respect to specific industries, but cannot readily be expanded to support the broad scope of GHG emissions regulations. CGE modeling results are very insightful, but lack the transparency and industry-level precision required to directly inform policy design.

III. Challenges in Calibrating Carbon Leakage Metrics

A comparison of Equation (2) and the two metrics that are currently used to assess leakage risk highlights some important discrepancies. First, current policy practice focuses on *domestic* emissions intensities whereas Equation (2) depends on *foreign* emissions intensities. Second, trade shares are used to proxy for the response of foreign output to the domestic policy.

A. Emissions Intensity

Ideally, a policy maker would know the emissions intensities of the foreign producers who would scale up production in response to any policy-induced reductions in domestic output.[3] This is difficult to assess ex ante for several reasons.

First, reliable measures of the GHG emissions associated with foreign production can be very difficult to obtain. In some cases, average emissions intensities are available at country-sector level. However, these sector-level averages can mask relevant heterogeneity (see Lyubich, Shapiro and Walker (2018) in this volume). If marginal emissions intensities vary significantly with the level of foreign production, average emissions intensities can provide a misleading measure of the marginal emissions response.

[2]For example, in the European Union Emissions Trading Scheme, emissions permits are allocated on the basis of output in sectors that exceed pre-defined thresholds for emissions intensity and trade exposure (see `https://ec.europa.eu/clima/policies/ets/allowances/leakage_en`). Other GHG programs, such as California's AB-32, have implemented similar output-based approaches.

[3]A comprehensive assessment of emissions leakage impacts would also account for transport emissions.

Second, even if detailed detailed data on foreign emissions intensities are available at the policy design stage, these parameters are likely endogenous. The introduction of a domestic policy can induce changes in emissions intensities as foreign firms respond to changing terms of trade and, potentially, reductions in the global prices of carbon intensive inputs.

In sum, ex ante estimation of the most policy-relevant measures of foreign emissions intensities is challenging. The average measures of domestic emissions intensity which are currently used to assess leakage risk are relatively easy to construct with available data, but imperfect. Work to refine these measures in ways that directly inform policy implementation would be valuable.

B. *Foreign Production Response*

A critical determinant of leakage risk is the extent to which a policy-induced reduction in domestic production leads to an increase in production abroad. In Equation (2), this foreign supply response is represented by $q^f_{it}\eta_{it}$, where η_{it} is the foreign supply elasticity with respect to domestic policy costs. Given data limitations, it is standard to approximate this foreign supply elasticity with a foreign *trade* elasticity.[4] In CGE modeling of emissions leakage, Alexeeva-Talebi, Löschel and Voigt (2012) find that even moderate variation in trade elasticity values can change the sign - and significantly affect the magnitude - of modeled leakage effects.[5]

Given the pivotal role of trade elasticities in leakage risk assessment and economic modeling, it is important to think carefully about how these parameters are estimated. Standard empirical strategies use time series and/or cross section variation in prices or costs to identify sector-specific trade elasticities. When specifying these estimating equations, several considerations need to be take into account.

A first consideration is the potential for aggregation bias. Aggregation of data across related sectors can improve precision, but abstract away from substantial heterogeneity in trade responses. To explore the potential for aggregation bias, Fischer and Fox (2018) (in this volume) use a gravity-style equation to estimate foreign import elasticities of substitution at the six-digit industry level. Using detailed U.S. trade data, they compare standard specifications at different levels of aggregation in order to inform the parameterization of more detailed leakage modeling and risk assessment for EITE industries.

A second consideration pertains to the source of identifying variation, which can differ substantively from the policy-induced variation of primary interest. In Fischer and Fox (2018) and the trade literature they extend, the main source of identifying variation comes from differences in transportation and trade costs across different foreign import suppliers. In an effort to improve the match between empirical context and the policy experiment of interest, in Fowlie, Reguant and Ryan (2016) we use variation in domestic versus foreign energy costs to estimate (separately) the responsiveness of foreign import supply and export demand. Although this source of identifying variation is relatively limited, it captures more closely the domestic input cost impacts that a domestic carbon price would induce.

Our estimating equation takes the following form:

$$\ln M_{it} = \eta_i \ln E_{it} + \mathbf{X}_{it}\beta + \epsilon_{it}, \tag{3}$$

where M_{it} is the value of imports in industry i and year t. E_{it} a measure of domestic energy costs, after controlling for foreign energy prices, macroeconomic trends and a battery of fixed effects. The response of imports, η_i is allowed to depend parametrically on industry characteristics such as energy intensity.[6]

A third consideration is the significant pa-

[4] This approximation will overstate leakage if changes in foreign imports or domestic exports are not fully reflected in changes in the total level of foreign production.

[5] Notably, modeling results are relatively more robust to variation in CO_2 intensities.

[6] We estimate an analogous set of equations for domestic exports. Reductions in domestic exports are another potential source of leakage, if reductions in domestic exports are replaced by foreign production.

rameter and model uncertainty which can complicate the integration of estimation results into policy design. Economic theory leaves much to be determined when it comes to precisely specifying Equation (3). And it can be difficult to isolate purely exogenous variation to achieve identification. Researchers must choose from a range of plausible functional forms and conditioning strategies. Assumptions about the structure of supply and demand can guide this choice - or misguide if assumptions misrepresent the true underlying relationships.

In light of these challenges, Fowlie, Reguant and Ryan (2016) estimate close to 200 plausible specifications for each outcome variable.[7] Figure 1 presents the distribution of import and export elasticity estimates for industries at three different points in the distribution of energy intensities. Whereas the signs are stable, the magnitude of these estimates depends substantially on how the estimating equation is specified. We find that exports are more responsive to the shock than imports (in absolute value), consistent with recent work that finds "micro" elasticities of substitution between foreign sources are larger than "macro" elasticities of substitution between domestic and imported goods (Feenstra et al., 2018).

Table 1 compares our estimated elasticities, calibrated to specific EITE sectors, with those found in Fischer and Fox (2018).[8] Industries are sorted in order of trade exposure (column (2)), the aforementioned standard proxy for trade responsiveness. Comparisons across methodologies reveal positively correlated elasticities, especially with respect to our import estimates. However, there are notable differences in both the magnitude of estimates within certain industries and the relative ranking of industries. Also, for almost all industries, our export elasticities are larger in absolute value.

There are a number of possible explanations for the economically significant differences in these industry-specific trade elasticities across columns (3), (4), and (5). One is that the response of trade flows to a relative change in domestic energy costs is materially different from the response of import flows from different trading partners to variation in tariffs and trade costs. It is key to further understand how import and export flows will respond to a policy-induced change in the cost of emissions intensive inputs. Another explanation is that our variation is more limited, and consequently our estimation strategy more parametric, potentially affecting the industry-specific estimates. Sensitivity of estimates to model specification choices is thus another important consideration in the calibration of leakage risk metrics.

IV. Discussion

The economics literature has made important progress in highlighting the theoretical potential for leakage and in assessing the potential for leakage risk under a range of conditions and assumptions. However, we currently observe only a tenuous connection between this academic research and real-world policy implementation.

In this short paper, we have used a simple formulation of emissions leakage to highlight some empirical challenges that seem particularly pressing from an applied policy perspective. First, refining estimates of the emissions associated with foreign production will be necessary in order to construct more theoretically consistent leakage risk metrics. Second, given the pivotal role of foreign output elasticities in the modeling and assessment of leakage risk, it is crucial to improve our understanding of these parameters. We have shown a high degree of correlation between estimates using different empirical approaches and identifying variation. However, economically significant differences in industry-specific elasticity estimates pose practical challenges in the calibration of sector-specific leakage risk metrics. Work that improves and refines our understanding of the foreign supply response

[7] Specifications vary in terms of how energy prices enter the equation, the extent to which we saturate the model with fixed effects, how we construct our measures of energy costs, or the set of interaction terms included.

[8] To facilitate a more direct comparison of trade elasticities across studies, we divide our elasticity estimates by the industry-specific share of production costs that is attributable to energy inputs. We effectively assume that an energy cost shock can be scaled up proportionally.

TABLE 1—FOREIGN OUTPUT ELASTICITIES

NAICS6	Sector	EI (1)	TE (2)	FF18 (3)	FRR16 Imports (4)	FRR16 Exports (5)
322110	Pulp Mills	0.10	0.51	4.75	[2.20, 5.20]	[5.90, 11.70]
322122	Newsprint Mills	0.21	0.47	4.50	[2.43, 3.43]	[4.14, 6.90]
327212	Other glass	0.14	0.41	2.46	[2.07, 5.00]	[4.71, 8.21]
325212	Synthetic Rubber	0.06	0.36	6.29	[3.33, 5.50]	[7.83, 17.33]
325199	Basic Org. Chem. Mfg	0.07	0.33	6.92	[3.29, 5.00]	[7.57, 15.00]
325311	Nitrogen Fertilizer	0.19	0.33	2.03	[2.58, 3.37]	[4.21, 7.37]
335991	Carbon and Graphite	0.08	0.32	4.66	[3.50, 5.75]	[7.25, 13.88]
327211	Flat Glass	0.19	0.28	3.99	[2.42, 4.26]	[4.32, 7.42]
325211	Plastics and Resins	0.06	0.23	6.24	[2.83, 4.67]	[7.67, 16.33]
321219	Reconst. Wood Mfg	0.10	0.17	1.85	[2.20, 5.30]	[1.50, 8.70]
327993	Mineral Wool Mfg	0.13	0.14	2.32	[2.46, 5.23]	[5.00, 9.69]
327213	Glass Container	0.18	0.14	2.19	[2.61, 4.39]	[4.33, 7.72]
322130	Paperboard Mills	0.16	0.12	4.13	[1.88, 3.63]	[4.50, 8.38]
311221	Wet Corn Milling	0.12	0.12	2.59	[2.50, 5.42]	[5.42, 10.42]
322121	Paper Mills	0.11	0.10	6.05	[2.91, 5.27]	[5.82, 10.91]
331511	Iron Foundries	0.08	0.10	4.87	[3.63, 5.00]	[6.75, 13.38]
327992	Mineral Earth	0.13	0.09	2.55	[2.62, 4.38]	[5.31, 10.08]
327310	Cement	0.26	0.07	-0.64	[2.46, 4.77]	[3.96, 6.31]
325110	Petrochemical Mfg	0.09	0.05	5.93	[2.56, 4.89]	[6.22, 12.67]
325193	Ethyl Alcohol	0.12	0.05	14.31	[2.83, 5.25]	[5.08, 10.83]
327420	Gypsum Product Mfg	0.16	0.04	3.08	[2.00, 3.56]	[4.38, 8.38]
327410	Lime Mfg	0.34	0.02	3.85	[1.97, 3.91]	[3.76, 5.09]

Source: Own elaboration based on results in Fischer and Fox (2018) (FF18) and Fowlie, Reguant and Ryan (2016) (FRR16). EI: Energy intensity, defined as Energy costs/total input costs based on detailed energy input data from the U.S. Census (see Fowlie, Reguant and Ryan (2016) for details). TE: Trade Exposure, defined as value of imports plus exports divided by domestic production plus imports, averaged for the years 2010-2014 using publicly available data from the U.S. Census. For ease of comparison, trade elasticities are presented in absolute value. Elasticities for imports and exports from Fowlie, Reguant and Ryan (2016) report the inter-quantile range for a variety of specifications. The correlation between FF18 and our median estimates (not reported in the table) are 0.54 and 0.45 for imports and exports, respectively.

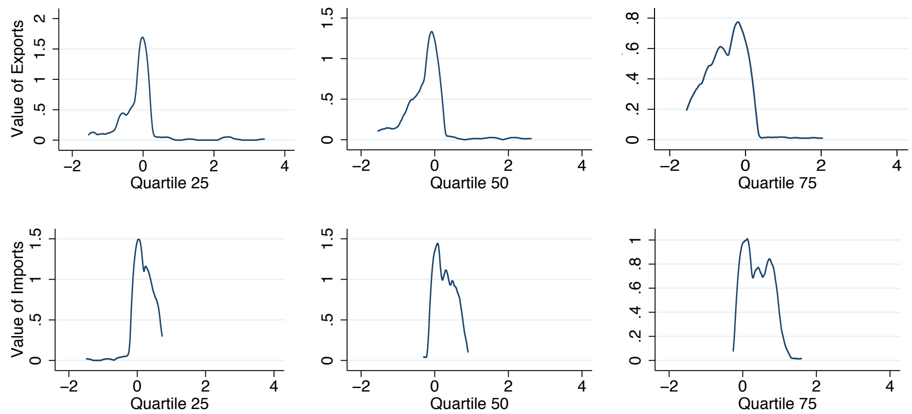

Figure 1. Estimating Foreign Output Elasticities

Source: Own elaboration based on Fowlie, Reguant and Ryan (2016). Each distribution represents a range of estimates for export and import elasticities across different quartiles of the energy intensity distribution from least (left) to most (right) energy intensive. Responses to domestic energy cost shocks are naturally negative for exports, positive for imports, and larger in absolute terms for the most energy-intensive sectors.

to incomplete GHG regulations is clearly needed.

Individual states cannot tackle the climate change problem on their own. Nor can they mitigate leakage with surgical precision. In light of the challenges and difficulties we discuss, it is tempting to throw up one's hands and advocate abandoning these incomplete efforts until a globally harmonized regulation can be implemented. But the urgency of the climate change problem warrants a more constructive response to the messy imperfections that inevitably manifest in regional GHG emissions policies. These challenges should be approached by economists with the same level of care and pragmatism that we have seen in the theoretical and practical development of other key standardized measures (e.g. GDP, PPP or IPC). Strengthening the link between academic research and policy implementation seems to us an exciting and important research agenda.

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