Environ. Sci. Technol. **2010,** *44,* 6563–6569

Primary and Embedded Steel Imports to the U.S.: Implications for the Design of Border Tax Adjustments

CATHERINE F. IZARD,*,[†],[‡]
CHRISTOPHER L. WEBER,[†] AND
H. SCOTT MATTHEWS[†],[‡]

Departments of Civil & Environmental Engineering and Engineering & Public Policy, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, Pennsylvania 15213

Received March 30, 2010. Revised manuscript received July 7, 2010. Accepted July 22, 2010.

Carbon Border Tax Adjustments (BTAs) are a politically popular strategy for avoiding competitive disadvantage problems when a country implements a unilateral climate change policy. A BTA taxes carbon embodied in imported goods in order to protect domestic industry and motivate other countries to implement climate change policy. To estimate the effectiveness of a BTA, is it is necessary to know which products are covered, where they were originally produced and ultimately exported from, and how the covered amount compares to total production in foreign countries. Using a scrap-adjusted, mixed-unit input-output model in conjunction with a multiregional input-output model, this analysis evaluates the effectiveness of BTAs for the case study of U.S. steel imports. Most imported steel by mass is embedded in finished products (60%), and 30% of that steel is produced in a different country than the one from which the final good is exported. Given the magnitudes involved and complexities of global supply chains, a BTA that protects domestic industry will be a challenge to implement. We propose a logistically feasible BTA structure that minimizes the information burden while still accounting for these complexities. However, the amount of steel imported to the U.S. is negligible (5%) compared to foreign production in BTA-eligible countries and is unlikely to motivate affected countries to impose an emissions reduction policy.

Introduction

In June 2009, the U.S. House of Representatives passed America's Clean Energy Security Act (*1*). ACES is the first bill that limits greenhouse gas (GHG) emissions and puts a price on carbon emissions to pass either chamber of Congress. (Note—we will use "carbon emissions" as a general term referring to all GHGs.) As with previous climate bills discussed in Congress, competitiveness concerns were a major sticking point during the negotiation of ACES. The fear is that if the U.S. acts unilaterally to place a price on carbon, domestic industry will face higher costs than their international peers and will be at a competitive disadvantage. In the worst-case scenario, U.S. industry would relocate to a country without mandatory emissions reductions. This "carbon leakage" would cost the U.S. jobs while failing to reduce global emissions.

Research in both the EU and the U.S. suggests that most sectors of the economy are unlikely to suffer competitive disadvantage as a result of a climate policy (*2*−*5*). However, energy intensive industries (EIIs), including steel, aluminum, pulp and paper, glass, and some chemicals, are vulnerable to competitiveness concerns (*3*). Without some kind of protection, prices could increase significantly for EIIs. For example, the iron and steel industry could see price increases ranging from 5−18% (*3, 4*). Such price increases could result in a decline in EII output of about 4% as result of climate change policy (*2, 6, 7*). The only empirical data available thus far about the effect of a carbon price on industrial competitiveness is from the E.U. Emissions Trading Scheme (EU-ETS). Reinaud (*8*) found that since EU-ETS came into effect, the aluminum industry in Europe has not been at a competitive disadvantage as a result of the EU climate policy, although she suggests that this may change once aluminum smelters are no longer protected by long-term electricity contracts predating EU-ETS.

Because of these concerns, policy makers have included protective measures for energy-intensive industries in proposed climate bills. There are several policy mechanisms available to protect industry from competitive disadvantage resulting from climate policy (*9*). ACES uses two: first, the bill rebates the cost of carbon to EIIs through free allocation of emissions allowances. Second, ACES requires importers of energy-intensive goods from countries without a climate policy comparable to the U.S.'s to purchase GHG emissions allowances equal to the amount domestic industry would have needed (*1*). This strategy, a type of Border Tax Adjustment (BTA), makes producers of both domestic and imported goods pay for their carbon emissions. Similar provisions are being discussed in the E.U., although this discussion will focus on the U.S.

Supporters claim that BTAs have two main advantages: first, they protect domestic industry from competitive disadvantage and prevent carbon leakage by making importers pay for the cost of carbon in their products. This levels the playing field between domestic and foreign producers on the domestic market. Second, because BTAs only apply to imports from countries without climate policies, they are a "stick" to motivate other countries to legislate a climate policy.

However, there have also been many arguments leveled against BTAs: they may trigger a trade war; they target emerging economies whose cooperation is vital for global climate policy; they only protect industry on the domestic (not export) market; and they may be illegal under the WTO. These considerable challenges have been discussed elsewhere at length (e.g. refs *4* and *9*−*12*).

In addition to these qualitative concerns, economic analyses have returned mixed results about the effectiveness of a BTA at preventing carbon leakage. These studies have largely used general equilibrium models to estimate the effects of a BTA on EIIs. Several studies have found that BTAs are potentially effective at preventing carbon leakage and protecting domestic competitiveness, although they appear to be most effective when both imports are taxed and exports are rebated (*7, 13*) and when emissions are calculated using sectoral averages in the country of production (*6*). Peterson et al. find that BTAs on primary materials not only protect EIIs but actually *increase* their output, although at the expense of downstream manufacturers and households, who see

---

* Corresponding author phone: (412)268-2940; fax: (412)268-7813; e-mail: cizard@andrew.cmu.edu.

[†] Department of Civil & Environmental Engineering.

[‡] Department of Engineering & Public Policy.

10.1021/es101010u

increased costs (*14*). McKibben and Wilcoxen find that BTAs do little to protect competitiveness or prevent carbon leakage and do not motivate foreign countries to implement climate policies (*15*).

When designing a BTA, policy makers must decide what types of products to cover. The products of concern are energy intensive materials (EIMs), which are produced by EIIs. Energy intensive materials (EIMs) are imported in two forms: primary and embedded. Primary EIMs include products made by energy intensive industries directly, such as steel tube or plate glass. Embedded EIMs are primary EIMs that have been further manufactured before being incorporated into another product, such as the steel in a kettle or the glass in a car window. The simplest BTA would cover only primary EIMs A comprehensive BTA would cover all EIMs, both primary and embedded. A BTA can also cover *all* products, regardless of their EIM content; however, this option has never been seriously discussed in U.S. policy and will not be considered here. Previous studies have either considered BTAs on only primary EIMs or on all products and have neglected the possibility of covering embedded EIMs (*6, 7, 13*–*15*). This is particularly relevant because the BTA in ACES covers primary and some embedded EIMS but not all products (*1*).

This paper uses a case study of U.S. steel imports to examine the importance of product coverage in determining the effectiveness of a BTA. Steel was selected as a case study because it has the highest energy intensity of the EIMs and is thus highly vulnerable to competitiveness concerns (*9*). We then use the results to discuss the logistical complexity of a BTA, which has rarely been addressed in the literature (*4*).

Methods and Data

In order to estimate the impact of product coverage on the effectiveness of a BTA for steel, several pieces of information are needed: the amount of primary and embedded steel imported and both where that steel was originally produced and from where it was ultimately exported. Data on primary steel imports are available from the American Iron and Steel Institute (*16*). Primary steel exports are assumed to be produced in the same country they are exported from. Quantifying the amount of steel embedded in imports is less straightforward. This paper presents a method for quantifying embedded steel imports using a modified Input-Output Analysis (IOA). A scrap-adjusted, mixed-unit IO model (SA-MUIO) is first used to calculate the amount of steel embedded in U.S. imports. A multiregional IO model (MRIO) is then used to calculate where that steel was originally produced. The model results in information about how much steel is embedded in imports, which products it is in, where it is imported from (as embedded steel), and where it was originally produced. While the SA-MUIO/MRIO model is applied to imports, it can be used to calculate the embedded steel in any arbitrary quantity of goods. This method can be used, with small variations, for other EIMs as well. Figure S1 in the Supporting Information shows the structure of the model.

An Input-Output (IO) model is a linear, static partial equilibrium model of the economy of the form

$$X = (I - A)^{-1} Y \tag{1}$$

Here, X is a vector representing the total economic output from each industrial sector in the economy. A is the direct requirements matrix or production structure of the economy. Each entry a_{ij} represents the output from sector i required to produce one unit of sector j. Y is the final demand matrix or the amount of industrial output for nonindustrial actors (i.e., households, government, etc.). I is the identity matrix. The total requirements matrix $(I\text{-}A)^{-1}$ represents the total, economy-wide requirements from row sectors to produce a unit of output from a column sector (*17*). A straightforward way to estimate the amount of embedded steel in U.S. imports is to treat imports as Y and use the IO model to calculate the total production required to produce those imports, X. The entry in X corresponding to steel would then be embedded steel imports. In the U.S., the Bureau of Economic Activity assembles IO tables from various industry statistics (*18*). These tables, as with most IO tables, measure purchases and production in economic units.

Unfortunately, there are several problems with using an economic model to calculate physical material consumption. First, due to the complicated structure of the steel industry, there are three sectors in the U.S. IO tables that produce primary steel products (*19*). Each of these sectors sells a significant fraction of its output to each other. This creates economic value that gets reported in the IO tables but does not create physical steel is used by the rest of the economy. Thus, converting directly from economic to physical units inflates the tonnage. Since this model is interested in the actual amount of physical steel in products and not the economic value created by trade within the steel industry, it is necessary to remove this intraindustry circularity.

The second problem with using economic data is that the IO tables report *purchases* of steel. Not all of this steel gets used in products—a large amount is wasted during manufacturing and sold back to the steel industry as scrap. For example, Wang et al. estimate that 13% of steel purchased for manufacturing is wasted during the manufacturing process and sold back to steel producers as scrap (*20*). In order to calculate embedded steel—the amount actually in products—it is necessary to remove scrap from the IO model. This prevents overestimating the quantity of steel actually in products.

It is possible to correct both of these problems by modifying the existing IO tables into SA-MUIO. While conventional IOA uses monetary tables, it is equally valid to use physical or mixed-unit tables as long as there is only one price for each commodity (*21*). Physical or MUIO analyses have been used since the energy crisis in the 1970s (e.g. ref *22*). Recently, they have been used to model the upstream material requirements or ecological rucksacks associated with economic activity (e.g. refs *23 and 24)*. Reference *25* uses MUIO to track the flows of heavy metals through the economy along supply chains, although it does not take into account waste production during the manfuacturing process and cannot be used to esetimate the amount of material in a given fininshed good. Reference *26* uses a waste IO model together with a material composition matrix to transform a monetary IO table (MIOT) into a physical IO table (PIOT) and applies the method to the Japanese economy. This approach takes into account manufacturing yield ratios and waste management and recycling. However, it is extremely data intensive, requiring information both to construct the waste IO model and the material composition matrices. Here we present a simpler, less data-intensive methodology for calculating the material embedded in finished products. While our approach requires stronger assumptions about manufacturing yields than (*26*), it is also possible to apply to countries that do not have as comprehensive data collection systems as Japan.

The SA-MUIO model starts with 2002 Benchmark Make and Use tables for the U.S., which have a 428 industry sector by 426 commodity resolution (*19*). 2002 is the most recent year for which Benchmark Tables (the most detailed available) are published. The tables are then modified into a MUIO as described in ref *27*. Here, the three monetary steel sectors are replaced by one physical steel sector to create mixed unit-tables. In the mixed-unit tables the consumption of physical commodities must be allocated to upstream users

TABLE 1. 2007 U.S. Steel Imports[a]

	steel exports to U.S. (Mt)			embedded steel product breakdown (Mt)			
	primary	embedded	total	transportation	industrial machinery	appliances, utensils, other equipment	other
Canada	7	9.1	16	6.1	1.5	0.4	0.8
Mexico	3.5	10	14	5.1	1.4	2.6	2.1
EU	5.1	12	17	4.9	4.7	1.0	0.8
China	6.3	13	19	1.5	2.8	5.4	3.8
rest of BRIC	4.9	1.0	5.9	0.4	0.3	0.1	0.1
Japan	1.7	9.2	11	5.6	2.4	0.4	0.5
rest of annex B	2	0.7	2.7	0.1	0.3	0.1	0.1
row	3	6.0	9.0	1.6	1.3	1.7	1.0
total	*34*	*61*	*94*	*25*	*15*	*12*	*9.2*

[a] Rest of BRIC = Brazil, Russia, India; rest of Annex B = countries with emissions reduction commitments under the Kyoto Protocol not otherwise listed; ROW = rest of world.

in the monetary sectors. We assume that consumers of physical commodities use the same proportion of physical commodity as they did of that commodity when it was represented in monetary terms. Physical data for steel production, trade, and use is available from refs *28* and *16*. 2002 physical data was used to match the IO tables. (See the Supporting Information for more on how the Make/Use framework is used to calculate the direct requirements matrix *A* and the MUIO is constructed from the Make/Use framework.)

The scrap adjustment assumes that all of the scrap produced by industries that purchase steel is steel scrap, with some common-sense adjustments. For these industries, the amount of steel purchased was reduced by the amount of scrap produced, and the amount of scrap produced was set to zero. In essence, this adjustment removes steel scrap from the economy altogether—the steel that would otherwise become scrap is neither purchased nor produced. More details are available in the Supporting Information. This SA-MUIO model was then used together with 2007 trade data (*16*) as *Y* and eq (2) to estimate how much embedded steel was imported from each of the U.S.'s trading partners in 2007.

In order to determine where the embedded steel imported to the U.S. was originally produced—as opposed to where it was imported from—it is necessary to use a MRIO model. MRIO is a form of IO in which trade is endogenzied by including trade and foreign production in the direct requirements matrix. A MRIO models the *global* production needed to produce a given final demand and can include any number of countries (*30*–*34*). References *35* and *36* provide a review of recent MRIO-based studies.

We use the input-output tables from GTAP 7 (*37*), a 113 country, 57 commodity model of global trade and production, compiled by ref *38*. The domestic production matrices for each country are modified using the same scrap adjustment made to the U.S. table in the SA-MUIO model, so that scrap production is not allowed. Because of some pricing difficulties associated with GTAP (*38*), GTAP was only used to find the *relative* foreign production shares for a given country's embedded steel exports to the U.S. *Total* embedded steel exports remain the result of the SA-MUIO model. (See the Supporting Information for more detail.)

There are several sources of uncertainty in this model. IOA has several inherent uncertainties, including but not limited to aggregation, the assumption of linearity, and source data accuracy (*39*). These are compounded by the modifications made here. The use of MUIO introduces uncertainty regarding the price-quantity conversion, since it assumes only one price for the physical commodities (*27*). The scrap adjustment introduces uncertainty in the amount of steel embedded in products, both due to the selection of which sectors to adjust and in the calculation of the waste-to-production ratio. The waste ratios calculated here were compared to similar ratios for the Japanese economy used in (*26*) for comparable sectors, and were found to be similar (*40*). We also tried to verify the amount of steel embedded in various product classes using estimates produced by the American Iron and Steel Institute (*41*). However, it was not possible to determine either how AISI made their estimates or which products were included. A useful comparison was thus impossible. When calculating the embedded steel in imports, the SA-MUIO model assumes that foreign economies have the same production structure as the U.S. This assumption is adequate for the purposes of this because it is reasonable to assume that U.S. imports have roughly the same material content as U.S. products do. More uncertainty is introduced by the use of MRIO in general (*36*) and GTAP in particular (*30*).

The uncertainties inherent in the analysis mean that it provides only first-order estimates. The model is useful for scoping the problems that may be associated with BTAs and for providing order-of-magnitude estimate of the quantities involved. It should not be used to calculate the embedded steel in a specific product.

Results and Discussion

The U.S. imported about 94 million metric tons (Mt) of steel in 2007, roughly the same as total domestic steel production (98 Mt (*42*)). The majority of this steel (60%) was embedded steel. Table 1 shows primary and embedded steel imports from each region and the steel embedded in various product types. The U.S.'s major trading partners are Canada, Mexico, China, and the E.U. The breakdown between primary and embedded steel exports varies by country. Canada and the rest of BRIC (Brazil, Russia, India) export a relatively large proportion of primary steel, while Japan exports almost no primary steel to the U.S. Most embedded steel enters the U.S. in transportation equipment and parts, although a significant amount is in industrial machinery and appliances.

Table 1 shows where U.S. primary and embedded steel imports are imported from. It does not describe where that embedded steel was originally produced. For example, steel may be produced in China, exported to Japan, manufactured into a car, and ultimately imported into the U.S. as embedded steel from Japan. This distinction is important because a BTA is applied to steel based on the policies of the country of *production*. The original country that U.S. steel imports are produced in is shown in Figure 1, which gives the amount of steel *production* in each region broken up according to the country that finally exports that steel to the U.S. (as embedded steel). The majority of U.S. embedded steel imports are originally produced in Japan, China, and the

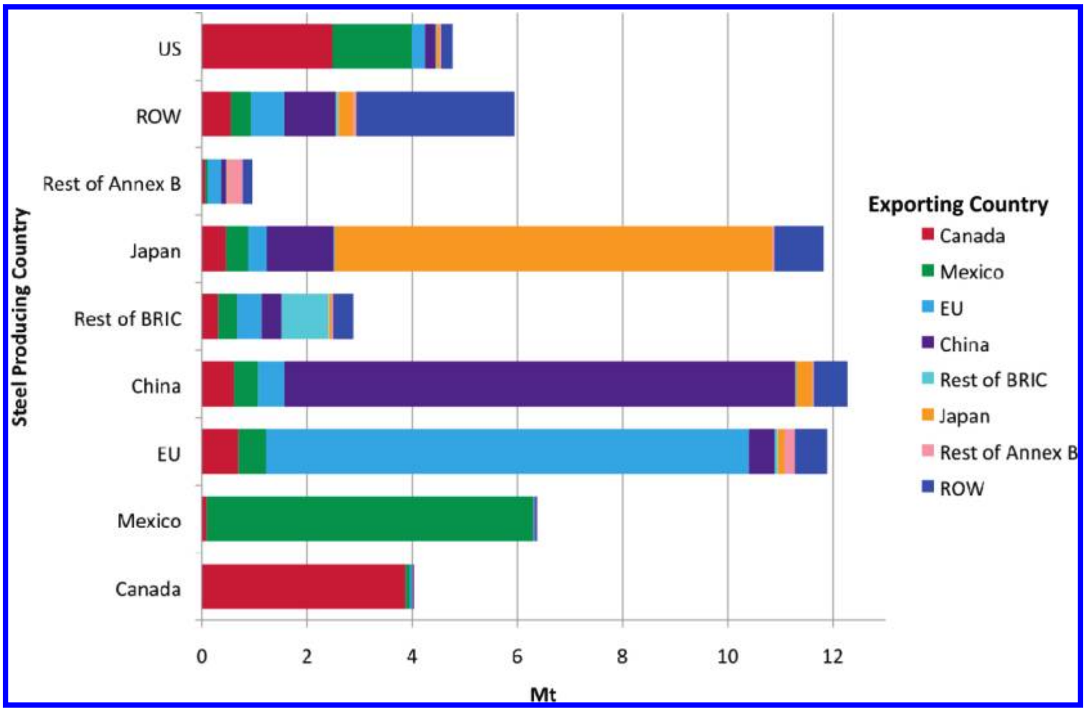

FIGURE 1. Country of production of U.S. embedded steel imports, broken down according to the country from which it was ultimately exported to the U.S.

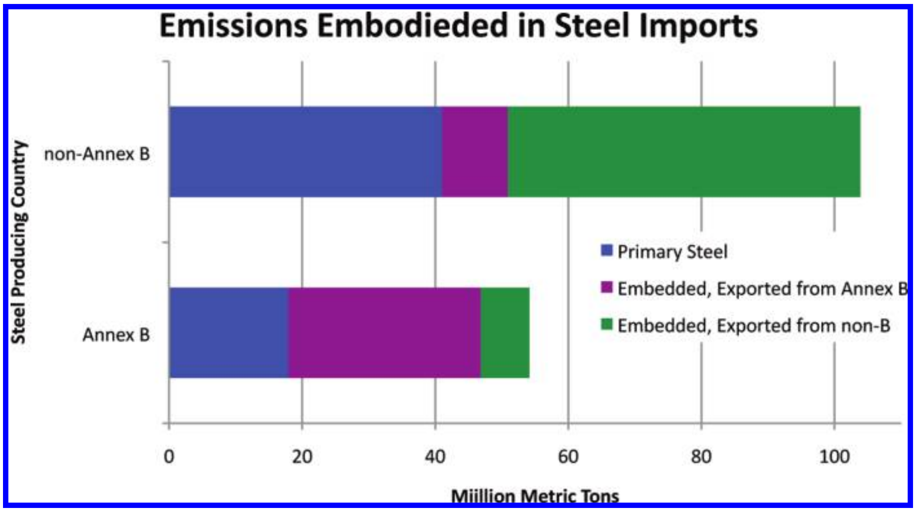

FIGURE 2. Emissions embodied in U.S. steel imports. Annex B = countries with emissions reduction requirements under the Kyoto Protocol, which are likely to be eligible for a BTA.

E.U. Trading patterns vary by country. Almost all Canadian- and Mexican-produced embedded steel is imported to the U.S. from those countries. In contrast, almost none of the embedded steel produced in the Rest of World (ROW) and Rest of BRIC reaches the U.S. from the region that produced it. Note that the U.S. produces about 8% of the embedded steel it imports. This steel is exported from the U.S. as primary steel, manufactured, and reimported as embedded steel.

The emissions associated with the production of steel for U.S. imports are shown in Figure 2. The emissions intensity of steel production in each region are from estimates in ref *9*. These estimates represent country averages (and therefore include the effect of the production process mix in each country). We use the distinction Annex B and Non-Annex B (as defined in the Kyoto Protocol) as a proxy for countries that are not likely to face a BTA and those that are, respectively. A BTA would only be applied to countries without a significant climate policy in place. In the case of the U.S., ACES requires countries to make "comparable" emissions cuts to the U.S (*1*). Of the regions in Figure 2, a BTA might reasonably be applied to China, Mexico, rest of BRIC, and some of the ROW. [The BTA in ACES exempts countries on the U.N.'s list of Least Developed Countries, most of which are in ROW. This is therefore a conservative estimate, since it includes all of ROW.]

In total, about 160 Mt of CO2 are embodied in U.S. steel imports. About 65% of this is embodied in steel produced in non-Annex B countries. This is disproportionally more than the amount of steel produced in those countries (about 50%). The difference is due to more emissions-intensive production technologies and electricity grids in non-Annex B countries. About 10% of embodied emissions are produced in a BTA-eligible country but exported through a noneligible country and vice versa.

ACES delegates the responsibility for designing the logistics of a BTA to the EPA administrator, although there are explicit instructions for the EPA to account for through-trade of EIMs (i.e., to ensure that, for example, Chinese steel is not exempted from BTAs by virtue of being embedded in a car imported from Japan) (*1*). One of the main concerns when developing a detailed BTA is whether it will be legal under the WTO. However, because any BTA may ultimately be subject to legal challenges, we proceed without consideration of legal issues.

As discussed above, there are two end points when considering product coverage for a BTA: primary EIMs or primary and all embedded EIMs. The level of product coverage will affect the effectiveness of a BTA at protecting domestic industry and motivating foreign countries to implement climate policies. In particular, a BTA on primary EIMs only may shift the competitiveness problem down the supply chain.

A BTA on primary EIMs only raises the price of both domestically produced and imported EIMs. Downstream manufacturers will bear this cost, putting them at a competitive disadvantage relative to their foreign competitors. While the strength of this effect depends on several factors, including the price elasticity of EIMs, the ability of manufactures to pass costs on to consumers, and the availability of substitutes, some downstream manufacturers may have a problem. Reference *14* found that a BTA on primary industries did indeed have a negative competitiveness effect on other sectors. The case study presented above shows that a BTA on primary steel only would cover about 17 Mt of steel imports or about 40% of total imports of steel produced in eligible countries (~20% of total steel imports). Such a BTA would also only cover about 40% of eligible embodied emissions (~25% of total emissions). The low product coverage of a primary steel only BTA suggests that a shift of competitive disadvantage from primary producers to downstream manufacturers may be enough of a concern to prevent a primary steel only BTA from achieving its goal of protecting domestic competitiveness.

Since a main goal of a BTA is to protect domestic competitiveness, a primary EIM only BTA seems like a poor choice, particularly in the case of steel—where only 40% of imports are primary. The other end point along the product coverage spectrum--covering both primary EIMs and all embedded EIMs--fixes this problem by protecting domestic industry all along the supply chain. ACES falls somewhere along this spectrum—some, but not all, embedded EIMs are covered. The EPA administrator will make this decision (*1*).

This type of BTA, while unambiguous, will be a logistical challenge. The "perfect" BTA design would tax the exact emissions embodied in every gram of every eligible EIM embedded in every imported product. In order to implement such a BTA, it is necessary to know the following: the amount of embedded EIMs in a product; where those EIMs were originally produced; and the emissions intensity of production. Because a BTA is tied to the climate policies of the country that produced the EIM, rather than the climate policies of the country that exported the final product, this information would have to be collected for *all* goods from all countries. Some manufacturers may have the first two required data points and could possibly require suppliers to track this information through the supply chain. However, this effort would require a significant investment in information management and reporting systems. Acquiring emissions data would require collecting new information.

The administrative costs of any BTA, and especially one that covers some embedded EIMs, are a significant concern. While there is not yet an estimate of the administrative costs of the BTA provision in ACES, the EU's Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH) legislation provides an order-of-magnitude comparison. This legislation requires all importers of goods into the E.U. to report quantities and toxicity data about chemicals in their products, similar to the quantity and emissions data that a BTA would require. Hartung and Rovida (*43*) estimate that REACH will cost companies €9.5 billion ($14.3 billion) over 10 years to administer, and this estimate does not include the cost of government administration. If the administrative burden of a BTA even approached this level, it could be a significant cost to importers on top of the tax itself. And because all goods would need to report the origin of their EIM content, the cost would fall on all importers, not just those importing from BTA-eligible countries. For comparison, a $15/t CO_2, a U.S. BTA on primary and embedded steel imports would have brought in about $1.5 billion in government revenue in 2007.

The information burden of such a BTA is quite high, and verification will be difficult. While a "perfect" BTA may be too expensive and logistically difficult to implement, other alternatives are possible. Figure S2 in the Supporting Information shows estimates of where the steel in US embedded steel imports was originally produced. One could propose a BTA in which the embedded steel in a product is taxed assuming that it contains the average of the exporting countries' steel mix. For example, it would be assumed that any car exported from Canada contains 40% Canadian steel, 30% U.S. steel, 7% Chinese steel, etc. Any Chinese car would be assumed to contain 75% Chinese steel, 10% Japanese steel, etc. The emissions associated with this steel could be calculated in a number of ways, including country average emissions intensity. Only the fraction of emissions from steel produced in eligible countries would have the BTA applied. Companies could then demonstrate, if they desired, that the steel in their products either a) came from a different country mix or b) was produced in a facility with a lower emissions intensity than the country average and have their tariff adjusted accordingly. This approach could be extended, using methodologies similar to those presented here, to all EIMs. For EIMs where data are less available than steel, however, extensive data collection efforts may be required no matter which BTA framework is chosen, as existing databases would not support this kind of analysis for rarer metals. This does imply one advantage of BTAs: increased data availability about material flows, which can help when designing effective strategic material stockpile and recycling strategies.

There are several advantages to this approach. First, determining the steel mix in each country that exports final products is far simpler than keeping track of the steel mix in every product and reduces the administrative burden on companies. However, this approach still does account for multiregional trade in the supply chain, as required in ACES. In this approach, it would not be possible to scam the system by importing Chinese steel through Japan, since that Chinese steel would be included in the average steel mix attributed to Japanese exports of embedded steel. Finally, because companies have the option to be exempted from the BTA by demonstrating that their products use a different or less emissions intensive steel mix, there would be incentive for manufacturers to select less emissions intensive suppliers.

The second goal of a BTA is to motivate other countries to establish emission reduction policies. Theoretically, countries will not want to have a BTA applied to their exports and will therefore develop a climate regime in order to get the BTA lifted. In order for this rational to apply, however, the taxed good would have to represent a significant fraction of production in the producing country. Otherwise, maintaining that market will not be worth the cost of emissions reduction for the entire sector. Figure 3 shows U.S. steel imports (primary [global primary steel production data from ref *16*] and embedded) from producing region in the context of total steel production in those regions. The U.S. imported about 7% of total global production in 2007. U.S. imports from BTA-eligible countries represent 5% of total production—an almost negligible amount. In fact, the only country

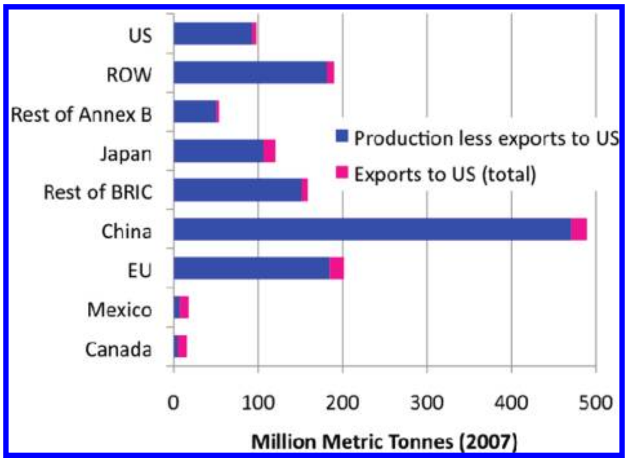

FIGURE 3. Global steel production and U.S. steel imports (primary and embedded). Figure from ref *44*.

for which a U.S. BTA might motivate climate action is Mexico. For most countries, including China, a U.S. BTA will probably not be adequate motivation.

BTAs are only one potential solution to the competitiveness issue. Rebates, free allocation, and sectoral agreements are all possible alternatives (*9*). Many have argued that BTAs are not the preferred alternative (e.g. refs *4 and 9−11)*, and here we show that they will be a logistical challenge to implement and may not serve the desired purpose of acting as a "stick". Despite these disadvantages, however, it seems that BTAs will be part of any climate bill the U.S. passes. Several key senators have announced that they will not support a climate bill that does not contain this kind of trade measure (e.g. ref *45*). Given this political support and because BTAs are not worth scuttling a climate bill over, it is worth considering how to design a logistically feasible BTA. For that purpose, an approach based on the EIM mix of the country of export may be a reasonable approach. The upfront data collection effort required by this scheme is manageable and could follow a methodology similar to the one presented here.

Acknowledgments

The authors would like to thank Belinda Bonds and Troy Hawkins and three anonymous reviewers for helpful comments. This work was supported by the Steinbrenner Institute of Carnegie Mellon University. The opinions presented here are strictly those of the author and do not represent the Steinbrenner Institute.

Supporting Information Available

Detailed methodology and Figure S2 of world embedded steel trade patterns. This material is available free of charge via the Internet at http://pubs.acs.org.

Literature Cited

(1) *America's Clean Energy and Security Act.* In 111 ed; 2009.

(2) Aldy, J.; Pizer, W. The Competitiveness Impacts of Climate Change Mitigation Policies. *Pew Center on Global Climate Change* **2009**, 1–56.

(3) Bassi, A. M.; Yudken, J. S.; Ruth, M. Climate policy impacts on the competitiveness of energy-intensive manufacturing sectors. *Energy Policy* **2009**, *37* (8), 3052–3060.

(4) Weber, C. L.; Peters, G. P. Climate change policy and international trade: Policy considerations in the US. *Energy Policy* **2009**, *372*, 432–440.

(5) IPCC. *Climate Change 2007: Mitigation.* Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change; Metz, B., Davidson, O. R., Bosch, P. R., Dave, R., Meyer, L. A., Eds.; Cambridge University Press: Cambridge, 2007.

(6) Mattoo, A.; Subramanian, A.; van der Mensbrugghe, D.; He, J. Reconciling Climate Change and Trade Policy. *World Bank Policy Research Working Paper # 5123* **2009**, 1–46.

(7) Manders, T.; Veenendaal, P. Border tax adjustments and the EU-ETS: A quantitative assessment. *CPB Netherlands Bureau for Economic Policy Analysis* **2008**, *#171*, 1–36.

(8) Reinaud, J. Climate Policy and Carbon Leakage: Impacts of the EU Emissions Trading Scheme on Al. 2008, 45.

(9) Houser, T.; Bradley, R.; Childs, B.; Werksman, J.; Heilmayr, R. Levelling the Carbon Playing Field. *Peterson Institute for International Economics and World Resources Institute* **2008**, 117.

(10) Asselt, H. V.; Brewer, T. Addressing competitiveness and leakage concerns in climate policy An analysis of border adjustment measures in the US and the EU. *Energy Policy* **2009**, *38* (1), 42–51.

(11) Zhang, Z. Multilateral trade measures in a post-climate change regime? What can be taken from the Montreal Protocol and the WTO? *Energy Policy* **2009**, *37* (12), 5105–5112.

(12) WTO, Trade and Climate Change. *World Trade Organization and United Nations Environmental Program* 2009, 1−194.

(13) Fischer, C.; Fox, A. Comparing Policies to Combat Emissions Leakage: Border Tax Adjustments versus Rebates. *RFF Discussion Paper* **2008**, 41.

(14) Peterson, E.; Schleich, J. Economic and Environmental Effects of Border Tax Adjustments. *Working Paper on Sustainability and Innovation No X1/2007, Fraunhofer Institute Systems and Innovation Research* **2007**, 45.

(15) McKibben, W.; Wilcoxen, P. The Economic and Environmental Effects of Border Tax Adjustments for Climate Policy. *Brookings Trade Forum, 2008/2009* **2008**, 1–37.

(16) American Iron and Steel Institute. *Annual Statistical Report 2007*; Washington, DC, 2008.

(17) Leontief, W. *Input-Output Economics*; Oxford University Press: New York, 1986.

(18) Horowitz, K.; Planting, M. *Concepts and Methods of Input Output Analysis*, updated 2009 ed.; U.S. Bureau of Economic Analysis: Washington, DC, 2006.

(19) BEA. *2002 Benchmark Input Output Tables*; Bureau of Economic Analysis: Washington, DC, 2007.

(20) Wang, T.; Mueller, D. B.; Graedel, T. E. Forging the anthropogenic iron cycle. *Environ. Sci. Technol.* **2007**, *41* (14), 5120–5129.

(21) Weisz, H.; Duchin, F. Physical and monetary input-output analysis: What makes the difference. *Ecological Economics* **2006**, *57* (3), 534–541.

(22) Casler, S.; Wilbur, S. Energy Input-Output Analysis--A Simple Guide. *Resour. Energy* **1984**, *6* (2), 187–201.

(23) Giljum, S.; Lutz, C.; Jungnitz, A. A multi-regional environmental input-output model to quantify embodied material flows. *GWS mbH, Vienna* **2007**, 1–35.

(24) Weisz, H. Accounting for raw material equivalents of traded goods: A comparison of input-output approaches in physical, monetary, and mixed units. *Social Ecology Working Paper 87, Institute of Social Ecology, Klagenfurt University, Vienna* **2006**, 1–31.

(25) Hawkins, T.; Hendrickson, C.; Higgins, C.; Matthews, H. S.; Suh, S. A mixed-unit input-output model for environmental life-cycle assessment and material flow analysis. *Environ. Sci. Technol.* **2007**, *41* (3), 1024–1031.

(26) Nakamura, S.; Nakajima, K.; Kondo, Y.; Nagasaka, T. The Waste Input-Output Approach to Materials Flow Analysis Concepts and Application to Base Metals. *J. Ind. Ecol.* **2007**, *11* (4), 14.

(27) Hawkins, T. A Mixed-Unit Input-Output Model for Life Cycle Assessment: Development, Uncertainty, and Application; Carnegie Mellon University: Pittsburgh, 2007.

(28) Fenton, M. Iron and Steel. In *Minerals Yearbook 2002*; United States Geological Survey: Washingon, DC, 2004.

(29) Census, U. S. *U.S. Imports of Merchandise, December 2007*; U.S. Census Bureau Foreign Trade Division: Washington, DC, 2008.

(30) Hertwich, E.; Peters, G. P. Carbon footprint of nations: a global, trade-linked analysis. *Environ. Sci. Technol.* **2009**, *43* (16), 7.

(31) Peters, G. P. From production-based to consumption-based national emission inventories. *Ecological Economics* **2008**, *65* (1), 13–23.

(32) Peters, G. P.; Hertwich, E. G. CO2 embodied in international trade with implications for global climate policy. *Environ. Sci. Technol.* **2008**, *42* (5), 1401–1407.

(33) Weber, C.; Peters, G.; Guan, D.; Hubacek, K. The contribution of Chinese exports to climate change. *Energy Policy* **2008**, *36* (9), 3572–3577.

(34) Weber, C. L.; Matthews, H. S. Embodied environmental emissions in US international trade, 1997−2004. *Environ. Sci. Technol.* **2007**, *41* (14), 4875–4881.

(35) Wiedmann, T.; Lenzen, M.; Turner, K. Barrett, j., Examining the global environmental impact of regional consumption activities — Part 2: Review of input-output models for the assessment of environmental impacts embodied in trade. *Ecological Economics* **2007**, *61*, 15–26.

(36) Wiedmann, T. A review of recent multi-region input-output models used for consumption-based emission and resource accounting. *Ecological Economics* **2009**, *69* (2), 211–222.

(37) Center for Global Trade Analysis. *Global Trade, Assistance and Production: the GTAP 7 Database*; Center for Global Trade Analysis, Purdue University: West Lafayette, IN, 2007.

(38) Peters, G. In *Opportunities and challenges for environmental MRIO modelling: Illustrations with the GTAP database*, 16th International Input-Output Conference of the International Input Output Association, Istanbul, 2−6 July, 2007; Istanbul, 2007; p 26.

(39) Lenzen, M. Errors in Conventional and Input-Output-based Life-Cycle Inventories. *J. Ind. Ecol.* **2001**, *4* (4), 127–148.

(40) Nakamura, S.; Nakajima, K. personal communication, 2009.

(41) American Iron and Steel Insitute. *Indirect Steel Trade 2007*; Washington, DC, 2008.

(42) Fenton, M. Iron and Steel. In *Minerals Yearbook 2007*; United States Geological Survey: Washington, DC, 2009.

(43) Hartung, T.; Rovida, C. Chemical regulators have overreached. *Nature* **2009**, *460* (27), 1080.

(44) Izard, C.; Weber, C.; Matthews, H. Scrap the Carbon Tariff. *Nature Reports Climate Change* **2010**, *4*, 10–11.

(45) Specter, A.; Levin, C.; McCaskill, C.; Hagah, K.; Johnson, T. Letter to President Obama. 2009.

ES101010U