

Climate policy and dependence on traded carbon

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Climate policy and dependence on traded carbon

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Abstract

A growing number of countries regulate carbon dioxide (CO₂) emissions occurring within their borders, but due to rapid growth in international trade, the products consumed in many of the same countries increasingly rely on coal, oil and gas extracted and burned in other countries where CO₂ is not regulated. As a consequence, existing national and regional climate policies may be growing less effective every year. Furthermore, countries that are dependent on imported products or fossil fuels are more exposed to energy and climate policies in other countries. We show that the combined international trade in carbon (as fossil fuels and also embodied in products) increased from 12.3 GtCO₂ (55% of global emissions) in 1997 to 17.6 GtCO₂ (60%) in 2007 (growing at 3.7% yr⁻¹). Within this, trade in fossil fuels was larger (10.8 GtCO₂ in 2007) than trade in embodied carbon (6.9 GtCO₂), but the latter grew faster (4.6% yr⁻¹ compared with 3.1% yr⁻¹ for fuels). Most major economies demonstrate increased dependence on traded carbon, either as exports or as imports. Because energy is increasingly embodied in internationally traded products, both as fossil fuels and as products, energy and climate policies in other countries may weaken domestic climate policy via carbon leakage and mask energy security issues.

Keywords: emissions embodied in trade, emissions from traded fuels, energy security, extraction, production, consumption, CO₂ emissions

 Online supplementary data available from stacks.iop.org/ERL/8/034011/mmedia

1. Introduction

Efforts to mitigate climate change begin with inventories of CO₂ emissions. There are three distinct waypoints where carbon can be reliably accounted: (1) where primary fossil fuels are extracted from the ground, (2) where fossil fuels are combusted (the conventional approach), and (3) where products made using fossil energy are ultimately consumed. We refer to emissions accounted for at these three points as extraction, production, and consumption emissions, respectively.

International agreements and existing climate policies pertain to production emissions within each country's sovereign territory (Houghton *et al* 1996). Yet the differences between such production emissions and consumption emissions are large and growing at the country and regional level (Peters *et al* 2011b), primarily due to products exported from China and other emerging economies to consumers in developed countries. In some countries where production emissions have been reduced, the alternative, consumption accounting perspective shows maintained or even increased emissions, because of increased net emissions embodied in trade (Peters *et al* 2011b). Similarly, countries like Australia and Norway regulate production emissions, yet meanwhile extract large quantities of fossil fuels that are exported to be combusted and add to territorial emissions accounts in other countries. To address these concerns, new regulation



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policies have been suggested, including supply side policies (Whalley and Wigle 1991, Harstad 2012), which would regulate emissions at the point of extraction, and border carbon adjustments (Böhringer *et al* 2012, Jakob *et al* 2013), which would either apply tariffs on imported goods according to their embodied carbon content, apply rebates for emissions charges associated with exported goods, or—most efficiently—a combination of the two (Fischer and Fox 2012).

Asymmetries in trade of fuels has long been recognized as an economic and geopolitical vulnerability (Yergin 2006). The rapid growth in the international trade of products further enhances this as the more dynamic trade in products can substitute for trade in fossil fuels via changes in production location. Regardless of where in the supply chain carbon is regulated, trade patterns will in many cases determine the effectiveness and economic impact of energy and climate policies (Davis *et al* 2011, Mansur 2012). Changes in international trade can mask energy security issues and cause unexpected carbon leakages.

Previous work has shown how flows of emissions embodied in traded products have changed over time (Peters *et al* 2011b, 2012), while other work has demonstrated accounting methods connecting international trade in fossil energy (coal, oil, gas) to international trade in products (Davis *et al* 2011). In this letter we integrate these two previous efforts by analysing harmonized accounts of CO₂ emission flows from point of fossil-fuel extraction to point of consumption of finished products over the period 1997–2007, permitting an analysis of trends, and we further combine these with metrics analogous to those originally developed in the context of energy security, to assess trends in the dependence of individual countries on foreign sources of carbon. In a world with rapid growth in international trade and fragmented implementation of climate policies, this facilitates an assessment of the changing vulnerability of countries to energy and climate policies in other countries that may be situated deep in the supply chain. We close by briefly discussing the implications of our work.

2. Methods

We harmonized economic, trade, and CO₂ emissions data from four versions of the Global Trade Analysis Project (GTAP) database (e.g., Narayanan *et al* 2012) for four different years: GTAP5.4 (1997, 78 regions), GTAP6.0 (2001, 87 regions), GTAP8.0 (2004, 129 regions), GTAP8.0 (2007, 129 regions). The harmonized dataset represented the global economy by 71 regions based on commonality of region definitions in all four versions. We include countries in the EU27 based on whether they were members at the start of 2013, regardless of membership in earlier years. Definitions of the regions are provided in supplementary table 1 (available at stacks.iop.org/ERL/8/034011/mmedia). Each of the four versions of the database divides each region into 57 sectors, and this detail is retained in the harmonized dataset for analysis.

We consider all energy flows in the units of the equivalent CO₂ emissions from the combustion of those fossil fuels to

make a stronger link of the energy flows to climate policy. Emissions of CO₂ are derived from energy volume data provided with the GTAP databases (in turn derived from IEA data McDougall and Lee 2006) using emission factors from Eggleston *et al* (2006), all in units of tCO₂/TJ: coal 94.6, crude oil 73.3, gas 56.1, and refined petroleum 69.7, along with oxidization fractions from Houghton *et al* (1996): coal 0.980, crude oil 0.990, gas 0.995, and refined petroleum 0.995. Compared to the conventional approach of considering fossil fuels in terms of energy content, using the carbon content amplifies the effect relative to gas of coal by 1.7 times and oil by 1.3 times.

For the analysis of the international trade of products we use an environmentally extended multiregional input–output table based on the GTAP database (Peters *et al* 2011a, Andrew and Peters 2013). The method of connecting trade in fossil fuels to emissions embodied in traded commodities (Davis *et al* 2011) is extended to allow analysis by fuel type (coal, oil, gas).

As an index of import diversity we use the inverse of the Herfindahl–Hirschman Index, which is itself calculated as $HHI = \sum_i p_i^2$, where p_i is the share of supplier i in the import mix. Our inversion of the index means that if n suppliers each supply the same proportion $1/n$ of total imports, our index would be n . Additional geopolitical factors such as reliability of individual sources and bloc behaviour of sources (which effectively reduces diversity) are not included in this analysis.

Further details of methods and uncertainty are provided in the supplementary information (available at stacks.iop.org/ERL/8/034011/mmedia).

3. Results and discussion

We find an across-the-board increase in carbon being traded internationally, both as fossil fuels and embodied in products, resulting from growth in international trade. Over the period of analysis, carbon in traded fossil fuels increased at an average rate of 3.1% yr⁻¹, from 8.0 GtCO₂ (36% of global CO₂ emissions) to 10.8 GtCO₂ (37%), while the carbon embodied in internationally traded products increased at an average rate of 4.6% yr⁻¹, from 4.3 GtCO₂ (20%) to 6.9 GtCO₂ (24%). Combined, traded carbon grew from 12.3 GtCO₂ (55% of global emissions) in 1997 to 17.6 GtCO₂ (60%) in 2007 (3.7% yr⁻¹).

Figure 1 shows fossil carbon is highly concentrated at each of the three different accounting points (extraction, production, and consumption), with the top-five regions at each point making up approximately two-thirds of global emissions throughout the period. In 1997 and 2001, the US held the top position under all three accounting methods: it was the largest extractor of fossil carbon, the largest emitter, and the largest consumer of embodied emissions. But in 2004, China took over as the largest global extractor of fossil fuels (figure 1(a)), as its domestic coal mining expanded in support of rapid industrialization (Minx *et al* 2011). By 2007, China had also displaced the EU27 as second-highest emitter of CO₂ (figure 1(b)). Positions of consumption emissions were more stable, with the US, the EU27, and China as first, second, and

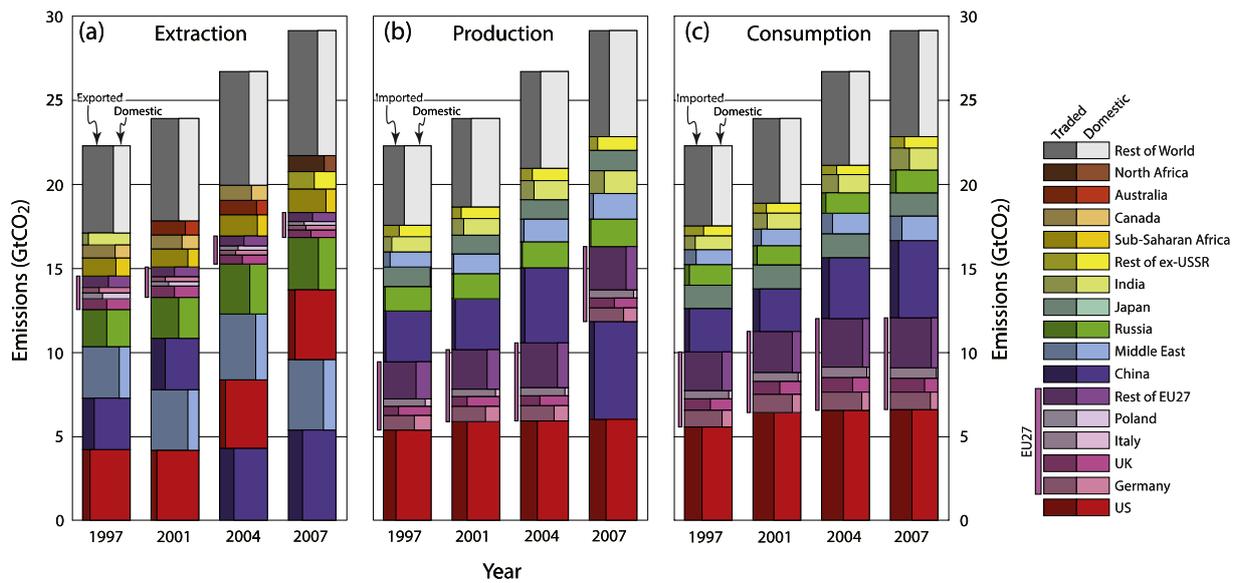


Figure 1. Fossil-fuel CO₂ emissions, 1997–2007, allocated to each of the three accounting points: (a) extraction (highlighting emissions embodied in domestic consumption and those consumed elsewhere), (b) combustion (highlighting whether the fuel was extracted domestically or elsewhere), and (c) consumption (also highlighting whether the fuel was extracted domestically or elsewhere). Countries in the EU27 are grouped.

third largest consumers of carbon, respectively, throughout the period (figure 1(c)). However, Chinese consumption emissions grew rapidly over the period, and other reports indicate that they surpassed those of both the EU27 and the US in 2009, and were 21% higher than those of the US in 2010 (Le Quéré *et al* 2013).

Energy self-sufficiency can be evaluated as the ratio of domestic energy extraction to domestic energy consumption. We adopt analogous metrics of carbon self-sufficiency: (i) the ratio of domestically extracted carbon to total carbon emitted during domestic combustion (figure 1(b)), and (ii) the ratio of domestically extracted carbon to total carbon embodied in all products consumed domestically (figure 1(c)). With these metrics, we assess the dependence of each country’s (i) energy use and (ii) overall consumption of products, respectively, on fossil carbon extracted elsewhere.

About one-third of fossil-energy use worldwide relies on imported fossil carbon. However, dependence of energy use on imported carbon increased markedly in the US and the EU27 between 1997 and 2007: from 27% to 35% in the US and from 55% to 69% in the EU27 (excluding trade within the EU; figure 1(b)). In contrast to the US and EU, a large majority of the fossil fuels combusted in China, Russia, and the Middle East are extracted domestically. Yet production emissions in China became significantly more dependent on imported carbon between 1997 and 2007, increasing from 5% to 10% over the period (from 150 MtCO₂ to 589 MtCO₂, mostly as traded oil).

Globally, consumption of products was more dependent on foreign sources of carbon than was energy use, and the proportion of consumption emissions reliant on carbon extracted elsewhere increased from 45% to 50% between 1997 and 2007 (figure 1). In some cases, carbon is extracted and exported to a different country where it is combusted

and embodied in products that are then imported back to the country where the carbon was originally extracted. When such path-dependent cases are included the fraction of consumption emissions dependent on traded carbon increases to 60% in 2007. European consumption is highly dependent on imported carbon, with an average 85% of consumption emissions imported in EU member countries, an increase from 77% in 1997. As a region, the proportion of the EU27s consumption emissions dependent on non-EU sources of carbon is large and growing, up from 64% in 1997 to 77% in 2007. Meanwhile, US consumption is less dependent on traded carbon than the global average, but growing: from 36% in 1997 to 46% in 2007. A much smaller proportion of Chinese consumption emissions were imported, but this amount has also grown steadily, from 10% to 17%. Further details of carbon flows between countries and regions, and their trends, are provided in supplementary figure 1 (available at stacks.iop.org/ERL/8/034011/mmedia).

Figure 2 illustrates trends in the net trade of carbon in fossil fuels (i.e. transfer from location of extraction to location of production, vertical axis) and embodied in products (production to consumption, horizontal axis) for selected countries. The potential economic impact of foreign climate policies increases with distance from the origin in figure 2, although different quadrants are susceptible to different types of regional policies, and elasticities of supply and demand will ultimately determine a given policy’s economic burden. As the original sources of traded carbon, the regions plotted in the upper half of the figure (e.g., the Middle East and Russia) are most susceptible to demand shocks from other countries’ policies that regulate emissions downstream either at the point of combustion (production emissions) or consumption. Regions in the right half (e.g., China) that export embodied emissions are similarly vulnerable to other countries’ policies

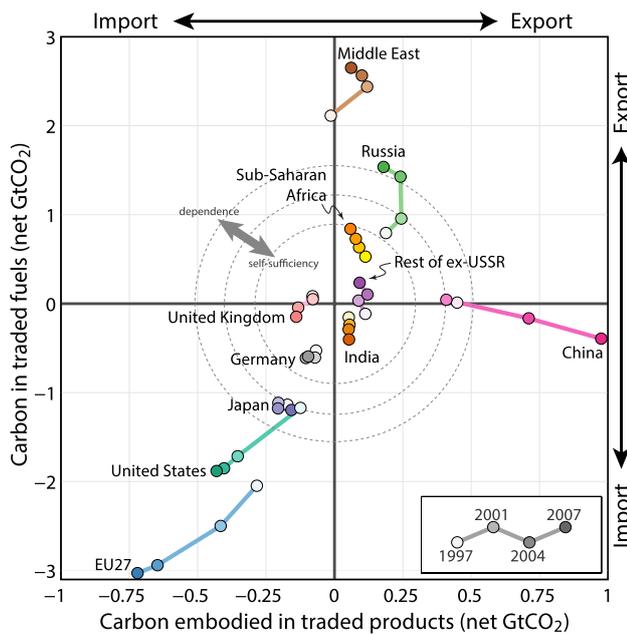


Figure 2. Net trade in fossil-fuel emissions for selected regions, showing both fossil-fuel trade and embodied emissions. A positive balance against the vertical axis indicates more fossil fuels exported for combustion elsewhere than imported. A positive balance on the horizontal axis indicates more domestic fossil fuels embodied in products exported for consumption elsewhere than foreign fossil fuels embodied in products imported. Note that the horizontal and vertical axes have different scales and the concentric circles are only for illustrative purposes.

that regulate consumption emissions or entail some form of border carbon adjustment. In contrast, the developed regions in the lower-left quadrant (e.g., the EU27, the US, and Japan) are exposed to disruptions in supply from other countries and a higher worldwide price of fuel carbon that might result from other countries’ climate policies imposed both at the point of extraction and of combustion. At the same time, the effectiveness and global influence of policies that regulate production emissions in these lower-left-quadrant countries is limited by their substantial reliance on carbon extracted and combusted outside their borders.

Movement away from the origin in figure 2 reveals that dependence on traded carbon is increasing in all the selected regions. Such increasing dependence was most evident in the EU27, where net imports of fuel carbon increased by 48% over the period (2.0–3.0 GtCO₂ yr⁻¹) and net imports of embodied emissions increased by 154% (0.28–0.72 GtCO₂ yr⁻¹). Over the same period, net imports of fuel carbon to the US grew by 60% (1.2–1.9 GtCO₂ yr⁻¹), while net imports of embodied emissions grew almost 250% (0.12–0.43 GtCO₂ yr⁻¹). Near-zero growth of the Japanese economy meant that its reliance on foreign sources of carbon grew very little over the decade. Increasing imports by the developed countries were balanced by increasing exports of carbon from Russia, the Middle East and China. Russia’s net exports of fuel carbon grew 93% (0.8–1.5 GtCO₂ yr⁻¹) and Middle East net exports of fuel carbon increased by 25% (2.1–2.7 GtCO₂ yr⁻¹). Meanwhile, China’s net exports

of emissions embodied in products increased by 117% (0.45–0.98 GtCO₂ yr⁻¹).

In addition to the magnitude of net trade in carbon, a country’s vulnerability to foreign climate policies (and its influence over foreign carbon) is also related to the diversity of its trading partners, which we measure as a combination of number and balance, as described in section 2. From an energy security perspective, increased diversity of trading partners is generally desirable because it tends to indicate reduced exposure to existing or potential undesired foreign policies or supply disruptions, although many factors other than simple diversity are known to determine security of energy supply (Cherp and Jewell 2011). From a climate policy perspective, diversity may have multiple interpretations depending on the goals of different countries and the way climate policies are implemented globally. If the policy goal is to regulate carbon emissions, then, because only a limited number of countries currently have carbon regulations, an increased diversity may increase the risk of carbon leakage making it more difficult to regulate those emissions. If carbon regulations cover more countries over time, then diversity of supply will have less relevance for climate policy. In sharp contrast, if the policy goal is to reduce economic loss, then increased diversity is likely to support that goal by spreading a country’s exposure to fragmented international carbon regulation. Thus, energy security and weakening carbon dependence may, at least in the short term, cause policy tensions due to conflicting goals.

Figure 3 shows the import diversity and dependence on imports of the US (figure 3(a)), the EU27 (figure 3(b)), and China (figure 3(c)), measured in terms of fossil carbon and differentiated by fuel type. Regardless of the type of fuel or trade path, the general shift to the right in figure 3 indicates that the US and the EU27 both became more reliant on imported carbon between 1997 and 2007. In general, the EU27 is more dependent on foreign carbon than the US. In both regions, trade in carbon embodied in globally sourced products had the greatest diversity of sources. In the US, the diversity in sources of carbon imported as oil and gas increased between 1997 and 2007 (blue and green EtoP paths), while diversity of imported coal decreased (red EtoP path). In comparison, the diversity in sources of carbon embodied in imported products (PtoC paths) was less directional, except in the case of embodied coal carbon, where diversity decreased over the decade as trade with China (which relies heavily on coal for its energy) became dominant (red PtoC path).

Trends in import diversity were more varied in the EU27. Diversity in sources of gas increased for both imports of fuel carbon (green EtoP path) and carbon embodied in imported products (green PtoC and EtoC paths), and the diversity of coal carbon embodied in imported products decreased (again reflecting the increase in products imported from China).

The dependence on foreign carbon in China is a strong function of fuel type. Overall, the extraction-to-consumption pathway (EtoC) shows increasing foreign dependence, with a relatively consistent diversity of suppliers. Diversity of supply for EtoC total is lower than that for both the EU27 and the USA. This is primarily a result of low import diversity for

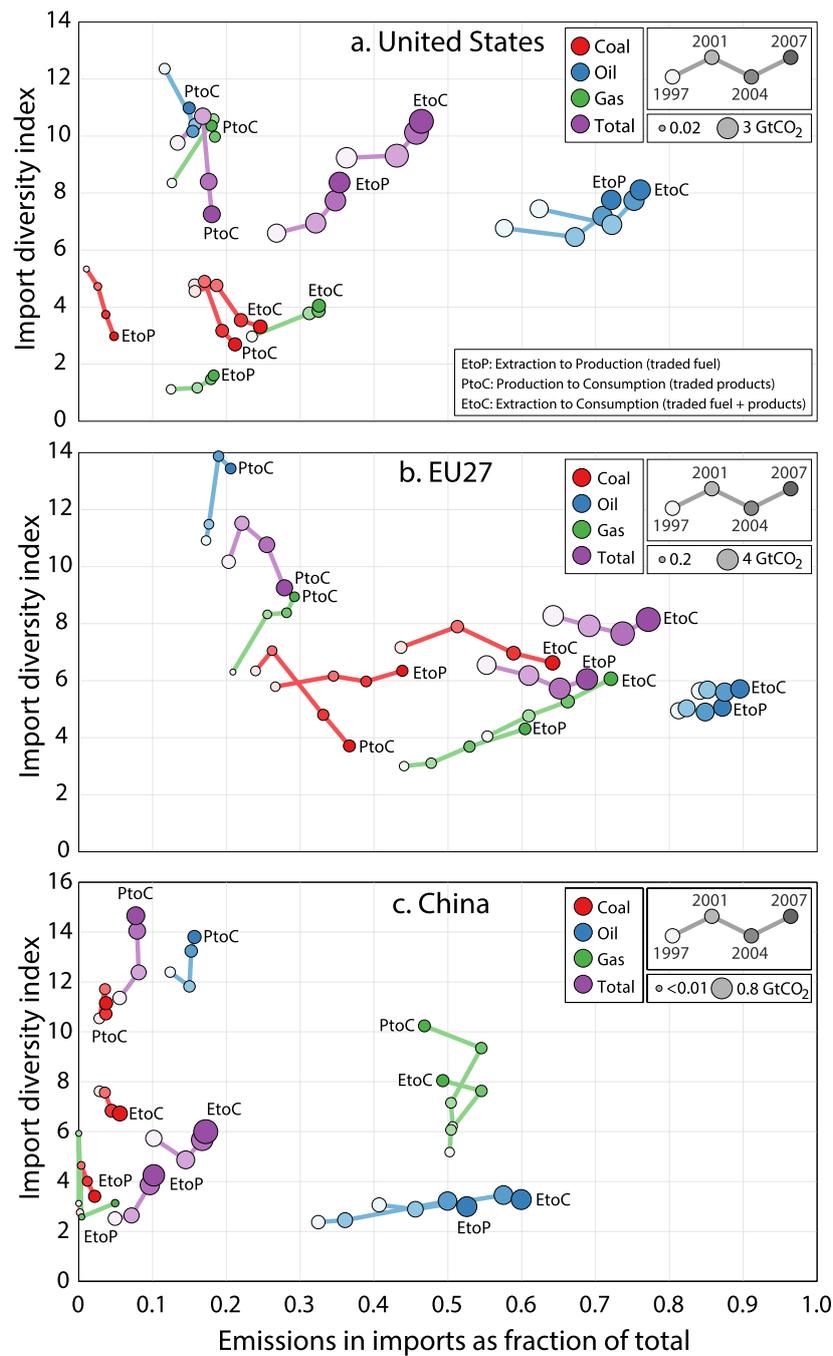


Figure 3. Diversity of import sources and proportion of supply imported for (a) the USA, (b) EU27, and (c) China by fuel type and supply chain component.

oil imports for domestic production. As with the EU27 and the USA, China's dependence on foreign carbon from oil has increased over the period, with domestically combusted oil from foreign sources increasing from 32% to 53% of total oil use. As China develops its domestic gas resource, dependence on imported gas has decreased relative to total use, but still increased in absolute terms.

4. Conclusions

The costs of a policy that regulates fossil carbon will be borne to some extent by all the parties in the supply

chain regardless of whether regulation occurs at the point of extraction, production (i.e. combustion) or consumption, although general equilibrium effects resulting from changes in quantities and prices complicate this picture (e.g., Jakob *et al* 2013, Lininger 2013, Böhringer *et al* 2012). Nevertheless, our analysis demonstrates in a new way the growing interdependence of countries via international trade, which has impacts on energy security and effective climate policy. In this second-best world of climate policy fragmentation, only a minority of global carbon emissions are regulated, and the strength of that regulation varies widely. What regulation there

is becomes less effective because of this growing dependence on foreign carbon. Furthermore, an increasingly integrated and lengthening global supply chain makes it more difficult to assess economic vulnerabilities to changing energy and climate policies in different countries. As countries with climate policy look to deepen their emission reductions, unilateral policies to reduce global emissions will be rendered less effective without an increase in the number of countries implementing such policies. Those countries without climate policies who are net emissions exporters, and the least developed countries who are net importers (Steinberger *et al* 2012), will be more exposed to foreign policies as more countries begin to consider and adopt carbon regulations (Lo 2012, Globe International 2013, Flannery *et al* 2013).

Without the access to the entire world's options for emissions abatement that global carbon regulation would provide, the global cost of abatement is increased (Weyant and Hill 1999). In addition to this loss of so-called 'where-flexibility' is the reduction in emissions covered by unilateral policy because of carbon leakage, whether strong or weak (Peters and Hertwich 2008, Droege 2011). Although some recent research suggests a consumption basis for policy is not guaranteed under all circumstances to reduce global emissions (Jakob *et al* 2013), countries whose consumption or extraction emissions are greater than their production emissions do not maximize their global influence when they adopt policies that regulate only those smaller production emissions. Even if climate policy continues to focus on production emissions, the use of complementary policy measures can enhance the global reach of domestic climate policies. Border carbon adjustments (Fischer and Fox 2012) may alleviate domestic competitiveness concerns about domestic emissions reductions, but may also encourage supplying countries to find ways to reduce their own emissions or, alternatively, encourage supplying countries to regulate their own carbon emissions (Helm *et al* 2012, Böhringer *et al* 2013, see also Barrett 1994, 2008). However, the consistency of border carbon adjustments with international trade agreements has not yet been tested and is far from certain (Fischer and Fox 2012), and, even if found to be consistent, the threat of trade wars remains (Barrett 2008). Supply side policies regulate emissions at the point of extraction and could be implemented as either a price (Whalley and Wigle 1991) or as a quantity measure (Harstad 2012). Since additional income from supply side policies would accrue to the extracting country, this may partially compensate for a drop in fossil-fuel prices due to climate policies in other countries (Whalley and Wigle 1991).

Current progress in climate negotiations suggests a willingness for policy makers to consider innovative ideas (Aldy and Stavins 2012), and given the growing importance of international trade for CO₂ emissions as well as a host of other environmental issues (e.g., Lenzen *et al* 2012, Dalin *et al* 2012, Meyfroidt *et al* 2010), it is critical that cross-border policy options are further explored and evaluated. In the meantime, developed countries' increasing dependence on foreign carbon means that their current production-focussed policies may be growing less effective every year.

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