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Carbon Embedded in China's Trade

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Abstract

A large fraction of China's greenhouse gas emissions are incurred in order to satisfy final demand of consumers in other countries; in effect, carbon emissions are embedded in China's exports. This paper explores the economic context and policy implications of carbon embedded in China's trade. China is a net exporter of embedded carbon because its entire economy is carbon-intensive; if China had its current trade patterns but U.S. carbon intensities in every sector, its net export of embedded carbon would disappear. China's success in trade is based on labor costs, not carbon emissions; there is literally no correlation between carbon intensity and revealed comparative advantage within the Chinese economy today.

In terms of policy, developed countries have discussed border tax adjustments on imports from countries with lower carbon prices. However, since China's comparative advantage is not based on carbon intensity, a border tax adjustment on carbon-intensive goods would do little harm to China, and would have little benefit for developed countries. A globally harmonized carbon price, often assumed to be crucial to successful climate policies, is not strictly necessary in theory, and may not be introduced for some time in practice. When and if it occurs, a harmonized carbon price will raise costs for China's carbon-intensive industries, but will also create an opportunity for China to "leapfrog" beyond the technologies developed in high-income countries and take the lead in creating the technological basis for a sustainable future.

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Introduction

China is both the world's largest emitter of greenhouse gases, and one of the world's largest exporters of manufactured goods. These two distinctive roles are of course connected: a large fraction of China's industrial production, and the ensuing carbon emissions, result from international trade. That is, greenhouse gas emissions depend on trade, since emissions located in China are often incurred in order to satisfy final demand in other countries.

Is the converse true as well? Is China's trade dependent on its high level of greenhouse gas emissions? It is sometimes assumed that China has a comparative advantage in carbon-intensive industries, i.e., the country is succeeding in trade *because* its export industries emit large amounts of greenhouse gases. If this were true, agreements to limit emissions would be an obstacle to China's exports, strengthening resistance to such agreements in China. Likewise, other countries would be reluctant to adopt domestic limits on carbon emissions until China does so, for fear of losing markets and industries to China's low-cost, high-carbon competition.

In reality, the picture is more complex. China is indeed a low-cost, high-carbon exporter, but its low costs do not depend on its high carbon emissions. Indeed, China's exports are not particularly concentrated in the highest-emission sectors. Section 1 of this paper shows that China's overall carbon intensity, rather than the industrial composition of its exports, is responsible for the huge net exports of embedded carbon. The carbon export surplus would disappear if each industry in China had the same carbon intensity as its U.S. counterpart.

A related finding is presented in Section 2: China's comparative advantage in world trade has no correlation with carbon intensity. This conclusion is supported both by the data on revealed comparative advantage and by the literature on the sources of China's success in world trade. Low-cost labor is an important basis for China's comparative advantage; low-cost carbon is not.

Turning to climate policy, developed countries are now debating the option of imposing domestic carbon prices, via cap-and-trade systems or carbon taxes. Such measures, it is often suggested, would leave industries vulnerable to unfair competition from countries like China with lower, if not zero, carbon prices. One common policy proposal, a border tax adjustment on imports from countries with lower carbon prices, is the subject of Section 3. Border tax adjustments, as currently discussed, would do little good for developed countries, and little harm to China. Only a handful of industries are heavily affected, and they are not, for the most part, ones in which China has a comparative advantage.

The final section addresses the broader implications of uniform world-wide carbon prices for countries such as China. Carbon prices need not be globally harmonized in theory, and may not be harmonized in practice for some time. When and if prices are harmonized, they will raise costs for China's carbon-intensive industries, but will also create a market opportunity for China to "leapfrog" beyond the carbon-saving technologies developed in high-income countries and take the lead in creating the technological basis for a sustainable future.

The quantitative analysis in this paper relies on the Multi-Region Input-Output (MRIO) model developed by Glen Peters and his colleagues, which has been widely used for analyses of carbon embedded in international trade (first introduced by Peters and Hertwich 2008).

Conforming to the data categories of the GTAP model of international trade, and building on the GTAP data set, the MRIO model provides consistent global estimates for domestic emissions, and carbon embedded in imports and exports, for 87 countries or regions, and 57 economic sectors in 2001.[1] This provides consistency and completeness, at the price of a somewhat dated data set. Since 2001, China's economy has grown rapidly, with increases in both the trade surplus and carbon intensity of production through 2006 (Raupach *et al.* 2007).

1. The carbon intensity of trade: three scenarios

By 2050 or sooner, if current trends continue, China will reach the level of per capita income in the United States today. That growth is sure to be accompanied by changes in technology and carbon intensity, perhaps moving toward U.S. patterns in some respects. What would happen to the carbon embedded in current trade patterns if each industry in China had the same carbon intensity as its U.S. counterpart?

China is currently less carbon-efficient than developed countries. That is, it has higher carbon emissions per dollar of output. As a consequence, exports from China are more carbon-intensive than almost all of the imports into the country. Economic growth, however, is likely to bring more advanced, carbon-efficient technology into use, and may therefore narrow the carbon-intensity gap between exports and imports.

To explore the effect of technological change and convergence in the carbon intensities of exports and imports, consider the following three scenarios for carbon embedded in trade:

1. Actual trade flows and emissions in 2001 (MRIO estimates).

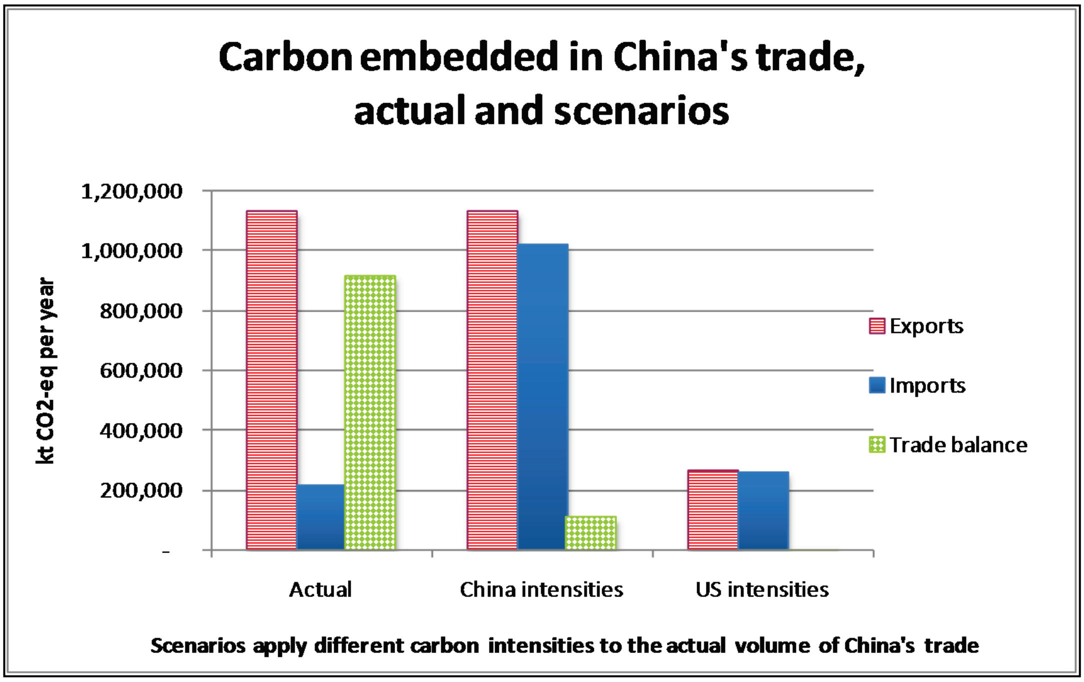
2. Actual trade volume (that is, dollar value of China imports and exports unchanged from scenario 1), but all imports produced at China's current carbon intensity in each industry.

3. Actual trade volume, but all imports, and all China exports, produced at the current U.S. carbon intensity in each industry.

The second and third scenarios are hypothetical and unrealistic; they serve only to separate the effects of carbon intensity from the effects of trade volumes. Figure 1 shows the carbon embedded in exports, imports, and the balance of trade in emissions under each of these scenarios.

[1] I would like to thank Glen Peters for generously sharing the data and results from his model; he is not responsible for the content of this paper, which is my analysis based on his work.

Figure 1



Under the first scenario, with actual carbon intensities for exports and imports, there is of course a large trade surplus: carbon embedded in exports far exceeds that in imports, so China is a large net exporter of carbon. However, if imports to China were produced at the same intensity as domestic production, the second scenario shows that the emissions trade balance would almost vanish: imports would embody almost as much carbon as exports. This is consistent with findings by other researchers; for example, Peters *et al*. (2007), examining China's carbon emissions, report that "There is a rough balance between CO_2 emissions from the production of exports and emissions avoided by imports." (p.5941) Emissions avoided by imports are the emissions that would have resulted from producing the country's imports in China, which is the same as the import emissions in the second scenario in Figure 1.

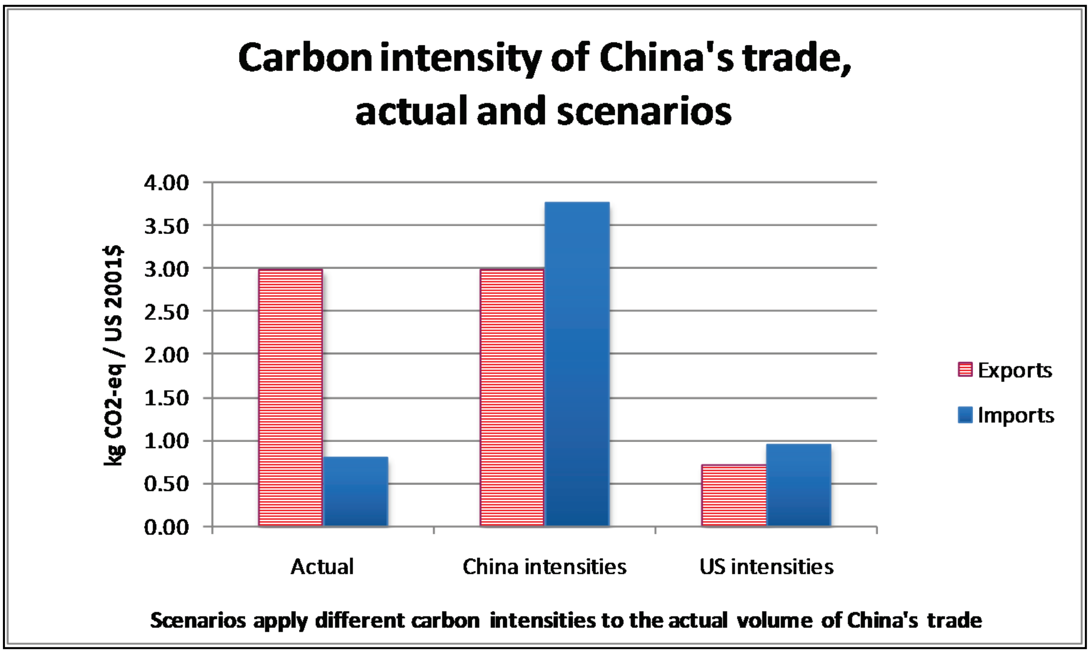
The third scenario shows that if China reached current U.S. carbon intensities while maintaining its current volume of exports, and its imports were also produced at current U.S. intensities, the carbon trade surplus would be close to zero. This scenario slightly increases the actual carbon embedded in imports, because many Chinese imports come from Japan and Europe, where carbon intensities are below U.S. levels.

The second and third scenarios both imply that, at equal intensities for imports and exports, China's trade surplus in embedded carbon would almost vanish – while by hypothesis, its monetary trade surplus would remain large. Everyone agrees that China has a sizeable trade surplus, but the amount is subject to dispute: the MRIO data set used in this analysis shows that China had a trade surplus of $108 billion in 2001; this is larger than the surplus reported by China, but smaller than the sum of the amounts reported by China's trading partners.[2] (See Table 1 below for trade balances for leading export sectors.)

[2] Chinese data show a trade surplus of $22.6 billion for 2001; reports from China's trading partners imply a surplus of $191.8 billion for the same year. The surplus grew rapidly after 2001, reaching $102.1 billion (China version) or $342.2 billion (partners version) by 2005 (Lum and Nanto 2007).

The combination, in scenarios 2 and 3, of roughly balanced trade in carbon with a big trade surplus in monetary terms is possible because at equalized sectoral intensities, imports to China would be more carbon-intensive than exports, as shown in Figure 2. In the first scenario, with actual carbon intensities, China's exports are far more carbon-intensive than its imports. But in either of the other scenarios – with each sector's intensity equalized worldwide either at China's intensities, or at U.S. intensities – the current mix of imports to China is on average slightly more carbon-intensive than exports from China.

Figure 2



This conclusion is perhaps unfamiliar, and deserves some emphasis: China's position as a net exporter of carbon does *not* result from exporting uniquely carbon-intensive products. Rather, China relies heavily on coal, and uses energy less efficiently than many of its trading partners. China is a net exporter of many manufactured goods, including both high-technology products such as electronics and machinery and traditional manufactures such as leather goods, apparel, and textiles. On the other hand, China is a net importer of chemicals, metals, minerals, and oil, among other things. At any one level of technology, either Chinese or American, China's imports would be more carbon-intensive than its exports. However, China's imports and exports are not produced at the same level of technology and carbon intensity.

How do carbon intensities by sector compare in China and the United States? China has higher emissions per dollar[3] in almost every industry, but there is no simple relationship between Chinese and American intensities.

Figure 3 graphs both countries' carbon intensities for each sector, with China on the horizontal axis, and the United States on the vertical. Figure 4 enlarges the lower left corner of Figure 3 (note the difference in scale on the axes). The diagonal red line represents equal

[3] Since the analysis involves international trade, all monetary amounts are based on market exchange rates, not purchasing power parity.

intensities in both countries; only oil seeds fall on the line, while a few other sectors such as paddy rice are close to it. In other sectors, China's carbon intensity is greater, often much greater, than the U.S. intensity. The round red dots (except for coal, these are shown only in Figure 4) are the sectors which account for more than 3 percent of China's total volume of carbon embedded in exports; they do not appear to be uniquely high or low in carbon intensity.

The most carbon-intensive sectors in China are energy sectors (coal, gas, electricity) and selected agricultural sectors (rice, meat); note that non-CO_2 greenhouse gases play a large role in agricultural emissions. The sectors named in Figure 3 – the only ones in which China's carbon intensity exceeds 10 kg of CO_2-equivalent per dollar of output – together account for less than 1 percent of the dollar value of exports: 0.81 percent for coal, and a combined total of only 0.11 percent for the other six industries.

Figure 3

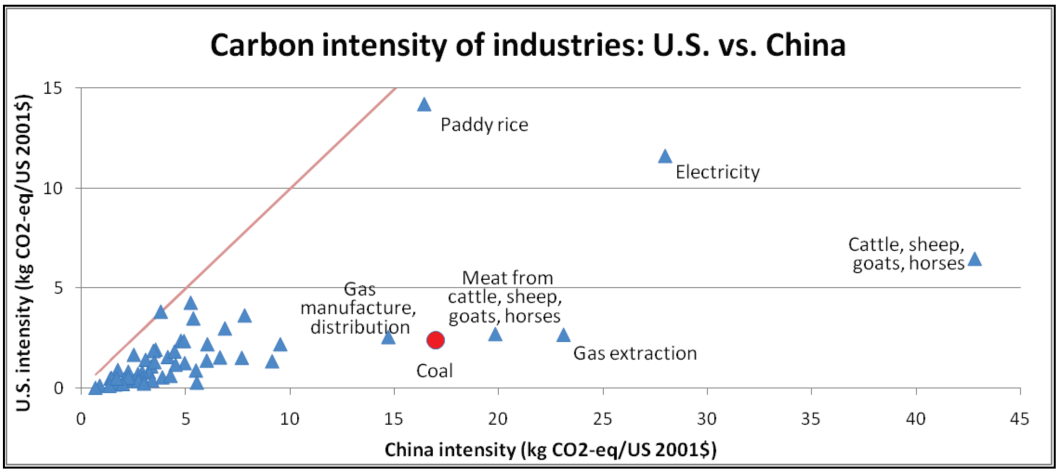
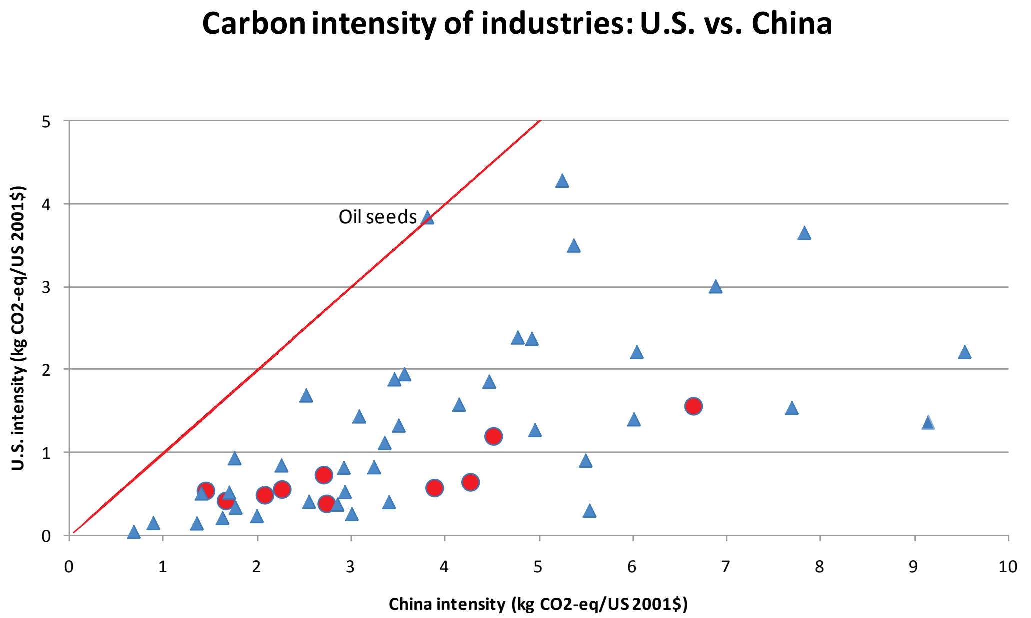


Figure 4



Round red dots are sectors accounting for more than 3% of the carbon embedded in China's exports as a whole. From left to right, they are: forestry, apparel, wood products, manufactures nec, textiles, transport equipment (excluding motor vehicles), leather products, metal products, chemicals rubber and plastics, and mineral products; see also the coal industry, shown in Figure 3.

2. Revealed comparative advantage and carbon intensity

China has of course been a remarkable success in world trade. And China has very carbon-intensive industries. This section explains why these two facts have little to do with each other: China's most successful export sectors are not its most carbon-intensive ones.

Economists frequently analyze trade in terms of comparative advantage. A country is said to have a comparative advantage in an industry if it has lower costs of production in that industry, relative to other sectors, than its trading partners. A country can usually maximize its income, at least in the short run, by exporting the products in which it has a comparative advantage. (Longer-run questions of development strategy are not addressed by this short-run calculation.)

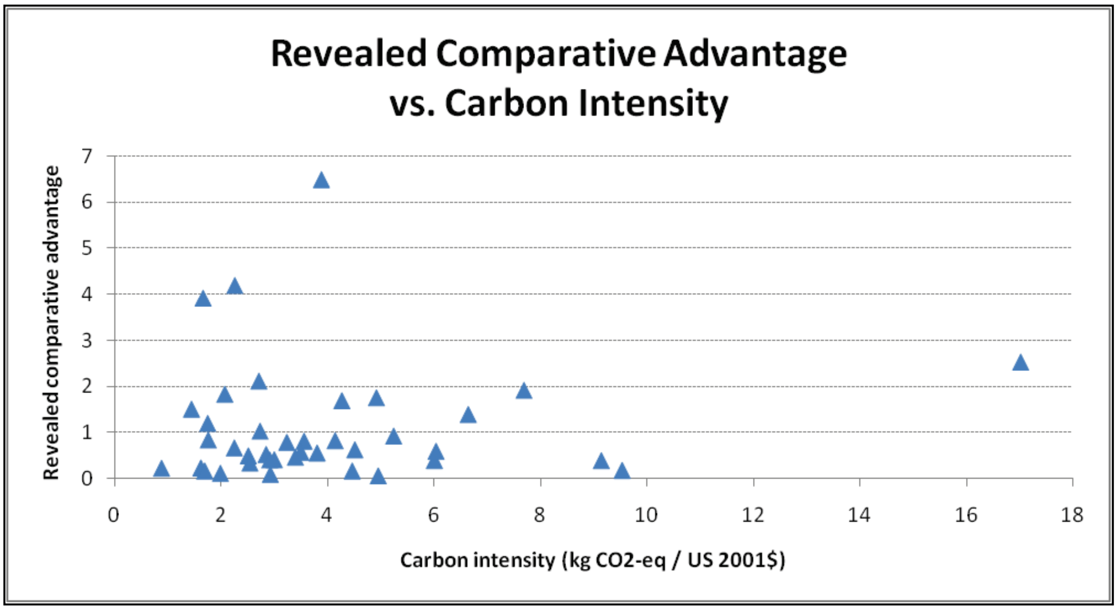
There is no obvious, direct measure of comparative advantage; instead, it has become common to assume that comparative advantage is revealed by success in trade. "Revealed comparative advantage" (RCA) is often measured by the Balassa index (first introduced in Balassa 1965): for China, the RCA for sector j is j's share of China exports, divided by j's share of all world exports. That is,

$$RCA_j = \frac{ChinaExports_j / ChinaExports_{ALL}}{WorldExports_j / WorldExports_{ALL}}$$

If $RCA_j > 1$, then sector j is more important in China's exports than in world exports in general; hence China is said to have a revealed comparative advantage in that sector.

There are 39 sectors that account for at least 0.1 percent of China's exports. For these 39 sectors, there is no correlation between RCA and China's carbon intensity, as can be seen in Figure 5. The same is true if, instead of China's absolute carbon intensity, RCA is compared to China's intensity relative to the United States, that is, the ratio of Chinese to American carbon intensity.[4] Using somewhat different data categories, my colleagues and I found a similar pattern in a study of U.S.-Japan trade: comparative advantage between the United States and Japan has only a weak, statistically insignificant correlation with greater carbon intensity.[5]

Figure 5



There are only 13 sectors with RCA > 1, i.e. sectors where China has a comparative advantage relative to world trade as a whole. Data on trade, emissions, and intensities for these 13 sectors are presented in Table 1. As the table shows, these 13 sectors account for 78 percent of exports in China, versus 42 percent worldwide. They also account for 70 percent of the carbon embodied in China's exports. In terms of net exports (in monetary terms), the 13 sectors account for 150 percent of China's positive balance of trade – since the other sectors of the economy as a whole are substantial net importers.

The 13 sectors, ranked in Table 1 according to the dollar value of Chinese exports, suggest a variety of bases for comparative advantage. The top three, representing 44 percent of exports, are all manufacturing sectors, combining modern (electronics) and unspecified (nec means

[4] In both cases, comparing RCA either to China's carbon intensity or to the China/U.S. ratio of carbon intensities, OLS regression shows that the adjusted r^2 is negative and $p > 0.5$, indicating *less* correlation between the two data series than would be expected by chance. The same is true in both cases if the coal industry, the extreme outlier in carbon intensity, is removed from the regressions.

[5] (Ackerman *et al.* 2007). The relationship between carbon intensity and the balance of trade was closer to significance in the Japan-US case ($p = .064$), but still explained only 2% of the inter-industry variance in the balance of trade.

"not elsewhere classified") activities. The next three, at 23 percent of exports, are traditional low-technology manufacturing sectors, namely textiles, apparel, and leather products. Note that leather products is the sector with the highest RCA, and apparel is third-highest. The next four sectors, accounting for almost 10 percent of exports, are resource-based sectors: wood, metals, minerals, and coal. Three small agricultural sectors, totalling less than 1 percent of exports, complete the list.

Judging by the list of 13 sectors, China's comparative advantage resides in a combination of advanced and traditional manufacturing, with only a minor role for natural resources. With the exception of the coal industry, none of these sectors are extraordinarily carbon-intensive. Indeed, the other economic sectors, where China does not have a comparative advantage, are on average more carbon-intensive than these 13.

Table 1

Sectors where China has a revealed comparative advantage

	Shares of total exports						
	China	World	RCA	Carbon intensity	Exports	CO2-eq in exports	Net exports
Electronic equipment	17.9	11.8	1.5	1.4	67,811	98,252	16,207
Machinery and equipment nec	15.3	14.8	1.0	2.7	57,874	158,362	10,744
Manufactures nec	11.2	2.7	4.2	2.3	42,573	96,302	39,976
Wearing apparel	8.9	2.3	3.9	1.7	33,650	56,065	31,049
Leather products	8.4	1.3	6.5	3.9	32,021	124,475	29,693
Textiles	6.0	2.8	2.1	2.7	22,660	61,506	5,879
Wood products	3.3	1.8	1.8	2.1	12,449	25,816	9,977
Metal products	3.2	1.9	1.7	4.3	12,136	51,833	9,406
Mineral products nec	2.3	1.6	1.4	6.6	8,655	57,503	5,534
Coal	0.8	0.3	2.5	17.0	3,055	51,976	2,983
Animal products nec	0.4	0.2	1.8	4.9	1,500	7,379	18
Processed rice	0.2	0.1	1.9	7.7	598	4,597	492
Fishing	0.1	0.1	1.2	1.8	510	894	441
All sectors with RCA > 1	77.9	41.8	1.9	2.7	295,492	794,960	162,399
All other sectors	22.1	58.2	0.4	4.0	83,975	334,181	(54,163)
Total	100.0	100.0	1.0	3.0	379,468	1,129,141	108,236

Units: Carbon intensity - kg CO2-eq / US 2001$ of output
Exports, net exports - millions of US 2001$
CO2-eq in exports - kt CO2-eq

nec = "not elsewhere classified"

These findings are consistent with the research literature on China's comparative advantage. Numerous analysts have focused on the role of wages and labor supply, assuming that China has a comparative advantage in manufacturing based on labor costs; this is often discussed in combination with government policies that have protected and promoted key industries. Fang Cai and Meiyan Wang (2006) focus on the demographic transition and project that China's working age population could start to decline within the next decade, a trend that could ultimately conflict with specialization in labor-intensive manufacturing. Gerard Adams *et al*. (2006) discuss the role of low-cost labor, exchange rates, and a range of other factors in explaining China's competitiveness. Xiaohui Liu and Chang Shu (2003) find that the export performance of Chinese industries is significantly influenced by labor costs, foreign direct investment, and firm size. Keun Lee *et al*. (2005) compare China to other rapidly developing East Asian economies, exploring the institutional framework for development and the interplay between "comparative-advantage-following" and "comparative-advantage-defying" strategies. Dani Rodrik (2006) argues that China has not simply relied on the comparative advantage produced by cheap labor; rather, government policy has helped to develop competitive industries in areas such as consumer electronics, making and exporting goods that would normally be produced by countries at a higher level of income. In this framework, future growth depends on China's ability to identify and promote higher-income products as it develops.

A rich understanding of Chinese economic success emerges from these analyses, among others; none of them mention energy, carbon intensity, or greenhouse gas emissions as an important factor in the country's development. China is developing at an unprecedented rate, and its economy is currently very carbon-intensive – but there may not be a close connection between these two trends.

3. Border tax adjustments: the debate

China currently has a large positive balance of trade – both in monetary terms, and in terms of the carbon embedded in trade. As the world moves toward policy measures and agreements that will place a price on carbon emissions, how will China's exports be affected?

One of the obstacles to action on climate change is the fear that if some but not all countries introduce a price on carbon emissions, either through a tax or through permit trading, they will place their industries at a competitive disadvantage. Other countries with lower carbon prices, or none at all, will have lower costs of production and could win an increased share of world markets. Carbon-intensive industries could migrate to carbon-tax-free locations, so that some part of the expected reduction in emissions would be lost through "leakage" out of the countries with carbon prices. A border tax adjustment is essentially a tariff on the carbon embedded in a country's imports, bringing the price of the embedded carbon up to the importing country's standard. This is intended to eliminate any unfair advantage from low carbon prices, at least within the importing country's own economy.

There are numerous practical problems with border tax adjustments. They would have to be differentiated by country of origin, since carbon prices could vary around the world. The taxes would also depend on elaborate calculations of embedded carbon: complex manufactured goods often contain components from more than one country, with differing carbon intensities and, perhaps, differing carbon prices. The focus here, however, is on the economic principles and impacts of border tax adjustments, not on the difficult details of implementation.

According to Joseph Stiglitz (2006), in a world that is trying to reduce emissions, failure to tax or otherwise price carbon could be considered an unfair subsidy, calling for a complaint to the WTO and the imposition of retaliatory tariffs against the non-compliant nation. At the time when this article appeared, the U.S. was increasingly isolated in its rejection of the Kyoto Protocol; Stiglitz presented his proposal as a justification for Kyoto-compliant countries to impose carbon tariffs on U.S. exports. Other authors making a case for border tax adjustments on grounds of efficiency and/or preventing carbon leakage include Demailly and Quirion (2006), Kopp and Pizer (2007), Ismer and Neuhoff (2007), and Goh (2004).

The specter of countries using differential carbon prices as a basis for applying tariffs on each other's goods raises fears that climate policy could become an excuse for a new protectionism. It is far from certain that carbon tariffs would be compliant with WTO rules; for analyses of this complex question see Hufbauer *et al*. (2009) and Werksman and Houser (2008). To minimize the practical problems and political resistance to border tax adjustments, attention has focused on targeting policies specifically to the most affected industries, where international differences in carbon prices could conceivably cause leakage of production and carbon emissions to lower-priced regions.

Emissions leakage, in significant quantities, can only occur in industries that are both internationally competitive and highly carbon-intensive. The list of such industries is surprisingly short, and relatively consistent around the world; they are generally the energy-intensive, primary materials industries. In the U.S. in 2002, just six industries accounted for 81 percent of manufacturing energy demand (and also for most of the non-energy process emissions of greenhouse gases from manufacturing):

- petroleum refining
- chemicals and plastics
- pulp and paper
- nonmetallic mineral products (including cement)
- ferrous metals, and
- non-ferrous metals.

These six industries represented only 2.5 percent of U.S. employment, and less than 4 percent of U.S. GDP.[6] The affected sectors may be a subset of these broad industry classifications (as suggested in Houser *et al.* 2008), implying that an even smaller fraction of the U.S. economy is at risk.

Even for the most directly affected industries, the impacts of differential carbon prices may be modest. An analysis by economists at Resources for the Future modeled the effect on the U.S. economy of unilateral U.S. adoption of a carbon price of $10 per ton of CO_2 (Ho *et al.* 2008). The increase in costs in the very short run, prior to any substitution of inputs or adjustment of production processes, was 5.0

[6] Calculated from data from U.S. Energy Information Administration (http://www.eia.doe.gov/emeu/mecs/mecs2002/data02/shelltables.html) and Bureau of Economic Analysis (http://www.bea.gov/industry/gdpbyind_data.htm); see also (Houser *et al.* 2008).

percent for cement, 4.2 percent for petrochemicals, between 1.0 and 2.6 percent for many other branches of the most affected industries, and less than 1.0 percent for the rest of the U.S. economy. In the long run, after industries adjusted to the change in energy costs, substantial losses occurred only in energy-producing industries; in all non-energy manufacturing sectors, the loss of employment was less than 0.7 percent, and the decrease in output was less than 1.3 percent.[7] Reduced demand for fossil fuels – which is the intended outcome of a carbon price – led to long-run declines in petroleum refining, coal mining, and oil and gas production, ranging from 4 to 10 percent.

A study of the European economy modeled a much greater carbon price (Manders and Veenendaal 2008). In its scenario with no trading with other countries, that study projected a permit price of €52 ($69) per ton of CO_2 in the industries covered by the European Trading System (ETS), and a carbon tax for other sectors of €29 ($39) per ton.[8] These prices, imposed unilaterally in Europe, led to a 3.2 percent loss of employment and a 4.5 percent loss of production in the ETS sectors – which represent 9 percent of total employment. Use of the Clean Development Mechanism (CDM) or a similar system for purchase of carbon reductions outside the EU allowed sharp reductions in these losses: unilateral European carbon pricing combined with use of CDM to obtain one-third of the reductions needed by ETS sectors (a limit based on current EU policy proposals) would lower the permit price to €27 ($36) per ton, and would lead to employment losses of only 1.2 percent and production losses of 1.7 percent in the ETS sectors. Another scenario, modeling a border tax on carbon-intensive imports in the absence of CDM, projected larger losses to ETS sectors than the CDM scenario.[9]

In short, the energy-intensive industries, where there is a credible competitive threat from countries with lower carbon prices, account for a very small fraction of the U.S. and European economies. Border tax adjustments targeted specifically to these industries would affect only a small fraction of world trade. If such policies are politically necessary to achieve a global agreement on carbon reduction, they should be carefully designed and limited to the affected industries, in order to avoid retaliatory tariffs and a retreat into protectionism. In his recent proposals for a "global deal," Nicholas Stern suggests that rich countries could offer assistance to developing countries in introducing new, lower-carbon technologies in energy-intensive industries, combined with imposition of carbon tariffs on those industries ten years after the agreement is signed, if developing countries have not established carbon prices or lowered emissions (Stern 2009). The delay would allow firms and developing countries time to adjust to the new market regime and the effects of carbon prices. This is, however, only a small part of what is needed to achieve global agreement on reduction, and it is probably not the most controversial part of the package.

A border tax adjustment, targeted to the most carbon-intensive, internationally competitive industries, would have surprisingly little effect on China. Of the six energy-intensive manufacturing sectors listed

[7] Non-energy mining is projected to lose 1.0 percent of employment and 1.1 percent of output in the long run.

[8] Currencies converted at €1 = US $1.33. The ETS covers electricity plus the six energy-intensive sectors of manufacturing listed above. The carbon tax of 29 euros was projected for the non-ETS sectors of the EU-15, i.e. the 15 members of the EU prior to 2004 – countries which generally have higher incomes than the newer members.

[9] This analysis is based on a general equilibrium model, in which total EU employment is arbitrarily assumed to be constant. As a result, it is difficult to obtain meaningful estimates of overall impacts on the European economy. On this and other limitations of general equilibrium modeling of international trade, see (Ackerman and Gallagher 2008).

above, Table 1 shows that China has a revealed comparative advantage in only one, non-metallic mineral products (which includes cement).

As shown in the top panel of Table 2 (next page), China's gross exports of $35.4 billion to high-income countries in the six energy-intensive materials industries represented 9 percent of its global total of $379.5 billion of exports in all sectors. The materials exports were widely distributed among high-income countries in geographic terms; by sector, chemicals and plastics accounted for more than half, followed by minerals.

Energy-intensive materials are not an insignificant category of exports, but they are not central to China's export success. That success is based on a comparative advantage in labor-intensive, rather than energy-intensive, industries. The great majority of China's exports are not in the most energy-intensive materials industries; the great majority of high-income countries' imports of these materials are not from China. Exports from China are a very small fraction of world supply of materials such as steel, cement, aluminum, and chemicals (Houser *et al.* 2008).

The six energy-intensive materials industries are large, diverse categories, such as chemicals and plastics. Within such categories, China exports some products and imports others. As the second panel of Table 2 shows, China is a net importer of the products of these six industries, from high-income countries and from the world as a whole; modest net exports in non-metallic minerals are outweighed by much larger net imports in the other five sectors.

Despite being a net importer of energy-intensive materials, China is a net exporter of carbon embedded in these materials, as shown in the bottom panel of Table 2. As explained above, China's exports are much more carbon-intensive than its imports, making it entirely possible to be both a net importer in dollars and a net exporter in carbon.

Trade with high-income countries represents most of China's trade with the world, as seen by comparing the last two columns of Table 2. The one major exception appears in the calculation of carbon embedded in net exports of ferrous metals, where China is a net exporter to high-income countries but a net importer from the world. This reflects large, carbon-intensive imports of ferrous metals from Russia and other parts of the former Soviet Union.

Table 2

China: exports of energy-intensive materials to high-income countries

	USA	Europe	Japan	East Asia	Other high-income	High-income total	World total
			Gross exports (millions of 2001 US $)				
Paper products, publishing	1,205	527	250	726	199	2,908	3,308
Petroleum, coal products	247	338	167	755	141	1,648	3,323
Chemical,rubber,plastic products	5,767	5,480	2,661	3,503	1,171	18,581	24,244
Mineral products	2,688	1,382	1,354	1,495	338	7,257	8,655
Ferrous metals	463	267	399	963	109	2,202	3,089
Other metals	340	421	505	1,438	111	2,815	3,361
Six-industry total	10,710	8,416	5,338	8,879	2,069	35,412	45,981
All industries, total	107,033	78,530	57,258	66,444	14,903	324,168	379,468
			Net exports (millions of 2001 US $)				
Paper products, publishing	332	(158)	(224)	(623)	(486)	(1,159)	(2,710)
Petroleum, coal products	117	224	85	(1,433)	108	(899)	(858)
Chemical,rubber,plastic products	2,300	1,034	(3,584)	(8,698)	70	(8,878)	(10,142)
Mineral products	2,329	866	357	580	319	4,450	5,534
Ferrous metals	(104)	(668)	(2,491)	(1,287)	(162)	(4,713)	(6,814)
Other metals	(413)	(436)	(880)	339	(946)	(2,335)	(4,069)
Six-industry total	4,560	861	(6,736)	(11,122)	(1,098)	(13,534)	(19,060)
All industries, total	78,033	26,623	8,694	(9,340)	4,332	108,342	108,236
			Carbon embedded in net exports (thousands of tons of CO2-eq)				
Paper products, publishing	2,801	1,031	210	1,144	(29)	5,157	3,501
Petroleum, coal products	1,203	1,833	678	1,306	770	5,790	8,936
Chemical,rubber,plastic products	21,873	22,046	2,080	1,120	4,308	51,427	54,684
Mineral products	17,298	8,435	1,036	7,511	2,197	36,476	49,879
Ferrous metals	3,461	1,042	(819)	5,836	(153)	9,367	(6,386)
Other metals	984	1,522	(5,147)	8,118	(4,954)	523	2,012
Six-industry total	47,620	35,909	(1,963)	25,034	2,140	108,740	112,627
All industries, total	271,850	198,247	142,788	174,877	21,844	809,606	850,344

Europe = EU-27, Switzerland, and Norway
East Asia = Korea, Taiwan, Singapore, and Hong Kong
Other high-income = Australia, New Zealand, and Canada

4. Does the world need harmonized carbon prices?

Beyond the detailed debate about energy-intensive industries and border tax adjustments, the effects of carbon prices can be considered in more general terms. On the one hand, a consistent worldwide price for carbon may not be necessary in theory or, in the short run, likely in practice. On the other hand, a harmonized carbon price would create both obstacles and new opportunities for China and other developing countries. The complexity of these issues emphasizes the need for climate policy to include much more than setting a price on carbon emissions.

It has become commonplace to call for a single global price of carbon, applicable everywhere. Price harmonization is thought to ensure efficiency in the worldwide distribution of abatement effort: with appropriate market institutions, investment in emissions reduction should flow to the countries where the costs of reduction are lowest. Fears about the effects of unharmonized carbon charges have slowed climate policy initiatives in some high-income countries, and have prompted the discussion of border tax adjustments, as discussed above.

Why, in theory, should the same carbon price apply everywhere? A single harmonized price, in a world of smoothly functioning international markets, would mean that investment in abatement would occur in every country, up to the point where the marginal cost of abatement equals the price of carbon emissions. No country would invest in abatement that was more expensive than the price of the abated carbon; at the same time, no country could profit by investing less, since all investments up to that cost would save money. Thus a globally harmonized price means that every country gives up the same dollar amount of consumption per ton of carbon avoided.

This theory could be criticized for assuming unrealistic perfection in the functioning of global markets for investment. More fundamentally, it also assumes that investment up to the same carbon price in every country is an equitable distribution of abatement costs. This would only be true if the same price for investment, such as US$20 per ton of carbon dioxide avoided, represented the same amount of human welfare in every country. In fact, $20 represents a much bigger change in welfare in low-income than in high-income countries. So the support for a harmonized carbon price rests on the unexamined assumption that the world income distribution is equitable – or equivalently, that increases in per capita consumption are equally urgent everywhere (Chichilnisky and Heal 1994; Sheeran 2006). In an inequitable world, equal sacrifice of human welfare per ton of avoided carbon requires higher carbon prices in richer countries, making it profitable for them to carry out higher-cost abatement efforts.

There is a possibility that the politics of climate negotiation will lead to a two-tiered price system, at least in the short run. As carbon allowance trading becomes more widespread in high-income countries, there may be moves to limit the amount of abatement that can be done overseas. Such limits are supported both by environmental moralism – we *should* be reducing our own carbon emissions, not just paying to reduce someone else's – and by economically parochial or protectionist sentiments – we should keep some of our emission-reducing investment at home to create jobs and incomes here, rather than sending it all to other countries. In an international trading system where high-income countries require a certain percentage of domestic abatement, there may be a higher price for domestic carbon allowances than for international ones.[10] As a result, higher-cost abatements will be undertaken in rich countries.

It is possible, however, that the momentum for a consistent worldwide carbon price will prevail in negotiations, at least for the long run. If this happens, developing countries will face a global carbon price, while local prices for labor, land and other inputs remain far below the levels of higher-income countries. Carbon emissions, or the credits for avoiding them, will account for a much larger fraction of

[10] Price differentials can only occur if the domestic abatement requirement is a binding constraint; that is, if an unconstrained market would have sold more international abatements than is allowed.

the value of production in lower-income countries. The potential dissonance between expensive carbon and cheaper local inputs creates both an obstacle and an opportunity.

The obstacle is that development may be distorted in the direction of activities that yield marketable carbon reductions. Even undesirable activities may be promoted in order to generate carbon credits. Safeguards are needed to prevent "carbon-allowance-seeking" investments; in any global carbon market, it will be essential to verify that emissions are not newly created in order to profit by reducing them. The temptation to seek such perverse allowances, unfortunately, is a natural consequence of a global carbon price in a low-cost local economy.

The opportunity created by this same pattern of prices is that much deeper reductions in carbon emissions will be economical in developing countries. In the simplest terms, saving a ton of carbon is "worth" more hours of labor at a lower wage rate. So there may be a category of carbon-saving investments and technologies that are profitable only in developing countries, where the tradeoff between carbon and other inputs is more favorable to emission reduction. With appropriate public initiatives and financing for these technologies, developing countries could "leapfrog" beyond the patterns of energy use in higher-income countries, establishing a new frontier for carbon reduction.

The potential for leapfrogging beyond the current technology frontier has been much discussed, but is difficult to achieve. The classic example is in telephones, where it is now possible to skip the expensive development of land lines and go directly to cell phones. This is not, however, an example of jumping to an entirely new technology; it became possible only after cell phones were invented and commercialized in high-income countries (Unruh and Carrillo-Hermosilla 2006). Likewise, research on the Chinese auto industry has found that the leading firms have shown little tendency toward leapfrogging beyond international standards; in fact, American auto companies, left to themselves, have often allowed their Chinese plants to lag behind their home-country technologies (Gallagher 2006). Strong government policies and initiatives are required to achieve the potential for newer, cleaner vehicle technologies. Even for a country with the extensive resources and market potential of China, there is much that needs to be done to reach this new technological frontier.

To realize the opportunity created by a global carbon price in low-cost economies, there will be a need for research and development in appropriate, cutting-edge technologies for carbon reduction. As with many of the new energy technologies that will be needed around the world, decades of public investment may be required before the developing-country technologies are successful in the marketplace. This is one important reason why carbon prices are necessary, but not sufficient, for an equitable solution to the climate crisis.

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