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# The carbon content of Japan–US trade

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**Abstract**

We analyze the greenhouse gas emissions embodied in trade between Japan and the US, extending the Japanese government's linked Japan–US input–output model to include carbon emission coefficients for each sector. We estimate that in 1995, Japan–US trade reduced US industrial emissions by 14.6 million tons of $CO_2$-equivalent, and increased emissions in Japan by 6.7 million tons, for a global savings of 7.9 million tons. These quantities are less than one percent of each country's total emissions. Trade with the rest of the world reduced emissions by much larger amounts, roughly four percent of each country's emissions. The sectoral patterns of carbon intensity are strongly correlated between Japan and the US; in addition, greater carbon intensity has a small but significantly positive effect on net exports. Policies that tax or otherwise regulate carbon emissions are needed to discourage this destructive route to competitiveness. However, the most important policy implication may be that US industry could cut its carbon emissions by more than half if it matched the environmental performance of industry in Japan.

*Keywords:* Input– output analysis; Carbon emissions; US–Japan trade

## 1. Introduction

Global economic integration adds a layer of complexity to national environmental policy. The large and growing volume of world trade implies that production and consumption of the same commodity are often located in different countries. It seems appropriate, in the abstract, for consumers to bear the responsibility for pollution created in the production process (among many others, see Munksgaard et al., 2005). Yet emissions are physically located in the producing country, and are conventionally treated and regulated as the responsibility of the producing rather than consuming nation. International agreements such as the Kyoto Protocol set targets based on the location of emissions, not on the location of final consumption that gives rise to the emissions.

A rapidly expanding literature addresses this question, often focused on the greenhouse gas emissions embodied in trade. It is now clear that the largest developed countries are net importers of carbon emissions, while developing countries as a whole, and a number of smaller, resource-rich developed countries, are net exporters of carbon.

Our research examines a new topic within this area: the carbon content of Japan–US trade. The massive trade flows between the world's two largest national economies are of enormous global importance, in both economic and environmental terms. Our goal is to determine whether one country is a net importer of carbon from the other, whether Japan–US trade reduces or increases total global emissions, and whether comparative advantage in trade between the two countries is associated with more or less carbon-intensive production.

## 2. Literature review

In the literature on trade and environment, a common conclusion is that developed countries displace a significant amount of their environmental load onto lower income countries. For instance, one study found that for six leading air pollutants (not including $CO_2$), both Japan and the US

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are net importers of embodied pollution; they have effectively displaced part of the environmental burden of their consumption onto the rest of the world. Western Europe is a net importer of embodied pollution for four of the six pollutants (Muradian et al., 2002). Other researchers (Wyckoff and Roop, 1994) have shown that 13% of total carbon emissions caused by consumption in the six largest OECD countries were due to carbon embodied in imports.

On the other hand, net exporters of embodied carbon include both middle income developing countries with emerging industries, and a few developed countries with resource- and energy-intensive exports. A study of the energy and carbon content of Brazil's imports and exports found a net export of about 7% of the country's carbon emissions throughout the 1990s (Tolmasquim and Machado, 2003). An OECD study estimated that in 1995, net carbon exports from China and Russia combined were roughly equal to net carbon imports of the OECD as a whole, or about 5% of OECD domestic emissions. Surprisingly, it also calculated that Brazil was a net carbon importer (Ahmad and Wyckoff, 2003, p. 21).

Although the OECD as a whole is a net carbon importer, individual countries vary widely. The same study, examining 20 large OECD economies, found net carbon exports from Australia, Canada, the Czech Republic, Denmark, Finland, Netherlands, Norway, and Poland; balanced carbon trade in Hungary; and net carbon imports into other countries, including the US, Japan, Korea, and all the largest European economies (Ahmad and Wyckoff, 2003, p. 8).

Other studies have reached similar though not always identical findings, with single-country analyses estimating significant net carbon exports from Australia (Lenzen, 1998), Norway (Hertwich et al., 2002; Peters and Hertwich, 2006), Sweden (Kander and Lindmark, 2006), and Finland (Mäenpää and Siikavirta, 2007); and approximately balanced carbon trade in Spain (Sánchez-Chóliz and Duarte, 2004), and Denmark (Munksgaard et al., 2005). Multi-country models allow the representation of more complex interactions between countries; this greater sophistication can be significant when modeling closely interconnected economies, as shown in a five-country study of Denmark and neighboring countries (Lenzen et al., 2004). For a valuable review of recent developments in this literature, see Wiedmann et al. (2007).

Several researchers have found that Japan is a net importer of embodied pollution from lower income countries. A study of Japan's trade with Asia/Pacific trading partners from 1981 through 1995 found that Japan was displacing a significant amount of pollution onto other countries in the region (Lee and Roland-Holst, 2000). A study of carbon emissions and trade between Japan and South Korea found that Korean exports to Japan are more carbon-intensive than Japanese exports to Korea (Chung and Rhee, 2001). Another analysis of Japanese trade found that Japan was still a net exporter of embodied $CO_2$ emissions in1975, but switched to become a net importer of embodied $CO_2$ before 1990 (Kondo et al., 1998). A recent study of 15 countries, including the US and Japan, confirmed that growth in GDP capita is the dominant factor driving growth in $CO_2$ emissions, outweighing the gains in energy and emissions efficiency (Lee and Oh, 2006).

Most important for our work, a study of carbon emissions and trade between Japan and Canada found that their bilateral trade reduces emissions in both countries (Hayami and Nakamura, 2002). Japan exports many manufactured goods, which it produces very efficiently with low carbon emissions, while Canada exports energy- and resource-intensive products such as paper and coal. Canada can produce these products with relatively low emissions, both because its abundant natural resources create a comparative advantage and allow efficient production, and because its extensive use of hydroelectric power means that carbon emissions per kilowatt hour of electricity are much lower than in Japan or most other countries.

Japan is a net importer of embodied pollution, despite a substantial trade surplus, because its imports are much more energy and carbon intensive than its exports. The US, in contrast, has relatively carbon-intensive exports but is also a net importer of embodied pollution due to its large trade deficit. A study of US–China trade found that the carbon embodied in US imports from China rose from 3% of US $CO_2$ emissions in 1997 to 6% in 2003. Because Chinese industry is less energy-efficient and uses more coal than US industry, global emissions were higher than if the US had produced the same goods domestically (Shui and Harriss, 2006).

An analysis of US trade and environmental impacts from 1974 through 2001 (focusing on five air pollutants, not including $CO_2$) found that the US imposed a growing environmental burden onto its trading partners; the growth in the volume of net imports has outpaced the decline in pollution intensity of both imports and exports (Cole, 2004). However, when looking specifically at US–Mexico trade, the same study surprisingly found that the US has been a net exporter of embodied pollution to Mexico since the late 1980s, and that Mexico's exports to the US have been declining in pollution intensity more rapidly than US exports to Mexico. That is, contrary to the usual pattern, Mexico has been displacing an increasing environmental load onto the US.

## 3. Research methods

Our research involved the extension of a two-country input–output (I–O) model to incorporate carbon coefficients for all economic sectors; in each scenario, we multiplied the model's estimates of output by the carbon coefficients to obtain greenhouse gas emissions from each sector. Input–output analysis was originated by Leontief (1941), and was extended to interregional and international trade applications in early contributions by Isard (1951), Chenery (1953), and Moses (1955).

Isard's formulation, which remains influential today, treats the same product made in different regions (e.g. Japanese cars and American cars) as different commodities, with their own rows and columns in the input-output matrix. Algebraically, consider two regions 1 and 2, and let **X** be the output vector, **A** the input coefficient matrix, and **F** the final demand vector; the paired subscripts *ij* refer to commodity flows from region *i* to region *j*. Then Isard's approach extends the familiar one-region I–O model as follows:

$$\begin{pmatrix} \mathbf{X}_1 \\ \mathbf{X}_2 \end{pmatrix} = \begin{pmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} \\ \mathbf{A}_{21} & \mathbf{A}_{22} \end{pmatrix} \cdot \begin{pmatrix} \mathbf{X}_1 \\ \mathbf{X}_2 \end{pmatrix} + \begin{pmatrix} \mathbf{F}_{11} \\ \mathbf{F}_{21} \end{pmatrix} + \begin{pmatrix} \mathbf{F}_{12} \\ \mathbf{F}_{22} \end{pmatrix}. \tag{1}$$

The solution, paralleling the standard single-region treatment, is

$$\begin{pmatrix} \mathbf{X}_1 \\ \mathbf{X}_2 \end{pmatrix} = \begin{pmatrix} \mathbf{I} - \mathbf{A}_{11} & -\mathbf{A}_{12} \\ -\mathbf{A}_{21} & \mathbf{I} - \mathbf{A}_{22} \end{pmatrix}^{-1} \cdot \begin{pmatrix} \mathbf{F}_{11} + \mathbf{F}_{12} \\ \mathbf{F}_{21} + \mathbf{F}_{22} \end{pmatrix}. \tag{2}$$

In this framework, a natural way to measure the effects of international trade is to set matrix blocks $A_{12}$ and $A_{21}$—representing each country's inputs into the other country's production processes—to zero, and then recalculate the output that would be required to satisfy the same final demand under those assumptions. As explained below, we calculated two such scenarios, to measure the effects of both bilateral and global trade on the US and Japan.

The principal drawback to this approach is the difficulty of developing the necessary, detailed data on interregional or international transactions. We were fortunate to be able to use the Japan–US international input-output table developed by the Japanese government. The Japan–US I–O table was first developed in 1990 by MITI, the industry and trade ministry (now renamed Ministry of Economy, Trade, and Industry, or METI); since then the Japan–US table has been used for a number of trade analyses. We used the 1995 I–O table, at its most detailed, 170-sector level.[1]

For each country we compiled a $CO_2$ emissions table, showing emissions per unit of output in each of the 170 sectors for which data were available. Emission factors were not available for 5 sectors in one or both countries; these were service sectors that are unlikely to have large carbon emissions. Standard I–O calculations, as represented in (2), estimate the induced demand that is attributable to final demand in each sector, i.e. the full range of inputs and indirect requirements that are needed to produce a unit of final product. With the addition of $CO_2$ emission factors for each sector, the model similarly estimates the induced emissions that are attributable to final demand in each sector, i.e. the emissions resulting from production of a sector's inputs and indirect requirements, as well as the sector's own emissions. These induced emissions for each sector form the basis for our analysis. An inherent limitation of this methodology is that it does not include emissions in other countries attributable to their exports to Japan and the US; we discuss some of the implications of this limitation below. We can calculate changes in Japan and US emissions, but not in world total emissions, attributable to trade flows.

The calculation of emissions by sector was based on fossil fuel use, as derived from the OECD's *Energy Balance of OECD Countries* 1995–1996. We calculated each country's fuel use in monetary terms from the I–O table, yielding a percentage distribution of fuel use by sectors. We then matched the I–O sectors to the corresponding energy balance sectors, applied the same percentage distribution, and obtained estimates for fuel consumption by sector in physical units. For scenario analysis, we assumed that each sector had a constant ratio of fuel use (and hence carbon emissions) to the value of shipments. Details of the calculation are available on request from the authors.

Using the Japan–US input output table and the related emission tables, we first estimated the total emissions of GHG in Japan, and in the US, induced by final demand in the two countries, and by exports to the rest of the world. This provides the "base case" for our analysis, representing actual conditions in 1995. Our base case estimates of industrial emissions in 1995 amounted to 4117.4 million tons of $CO_2$ in the US, and 1052.0 million tons in Japan. The industrial sectors included in our analysis account for most but not all of the greenhouse gas emissions from both countries: total US emissions in 1995 were 6482 million tons of $CO_2$ equivalent, while the Japanese total was 1321 million tons.[2] Thus the I–O model base case accounts for 63.5% of total US emissions, and 79.6% of Japan's emissions. (Our model excludes non-industrial emissions, such as emissions from gas and oil-fired home heating, as well as emissions from personal or non-business motor vehicle use.)

We then compared the base case results to the emissions in two other scenarios, repeating the I–O calculations under hypothetical, "what if" assumptions:

- Scenario 1, a "no Japan–US trade" scenario, where each country produces at home the goods that are now imported from the other country (leaving all other assumptions and trade flows unchanged); and
- Scenario 2, a "no foreign trade" scenario, where both the US and Japan eliminate all imports and exports and produce at home the goods that are now imported from all other countries.

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[1] This was the latest available table at the time when we began our research.

[2] Totals for all greenhouse gases, excluding land-use change and forestry, from national inventories of greenhouse gases submitted to the United Nations Framework Convention on Climate Change; see Greenhouse Gas Inventory Office of Japan, http://www-gio.nies.go.jp/aboutghg/nir/nir-e.html.

The difference between emissions in the base case, with trade, and scenario 1, without trade, represents the emissions attributable to Japan–US trade. If emissions are smaller in scenario 1 than in the base case, then bilateral trade has increased emissions; if emissions are larger in scenario 1 than in the base case, then trade has reduced emissions. In exactly the same way, the difference between emissions in the base case and scenario 2 represents the emissions avoided or created by all foreign trade for Japan, and for the US.

Note that for both scenarios 1 and 2, the difference between scenario and base case emissions is a purely domestic, single-country measure: it is the domestic emissions avoided by imports, plus the domestic emissions created by exports. It does not measure the foreign emissions actually created by other countries' exports to Japan or the US. For example, scenario 2 assumes, among other things, that the US has no trade with China. It therefore includes the emissions that would have been generated by production in the US of everything that is actually imported from China; it also excludes the emissions actually generated by everything exported to China. It does not include any estimate of emissions in China related to trade with the US.

The sum of US emissions avoided by imports, minus US emissions attributable to exports (for all trading partners, not just China) is the difference between scenario 2 and base case emissions. The same logic, of course, applies to Japan's emissions in scenario 2 versus the base case. Similarly, the difference between scenario 1 and the base case includes each country's emissions avoided by imports, minus emissions attributable to exports, for US–Japan trade in particular.

In the algebraic formulation introduced above, let the subscripts $J$, $U$, and $R$ stand for Japan, US, and rest of world, respectively. The base case is simply Eq. (2), with subscripts 1 and 2 replaced by $J$ and $U$. Scenario 1, assuming no bilateral trade between Japan and the US, is expressed as

$$\begin{pmatrix} \mathbf{X}_J \\ \mathbf{X}_U \end{pmatrix} = \begin{pmatrix} \mathbf{I} - \mathbf{A}_{JJ} - \mathbf{A}_{UJ} & 0 \\ 0 & \mathbf{I} - \mathbf{A}_{JU} - \mathbf{A}_{UU} \end{pmatrix}^{-1} \times \begin{pmatrix} \mathbf{F}_{JJ} + \mathbf{F}_{UJ} \\ \mathbf{F}_{JU} + \mathbf{F}_{UU} \end{pmatrix}. \tag{3}$$

Similarly, with the natural extension to a three-region model, scenario 2 is expressed as

$$\begin{pmatrix} \mathbf{X}_J \\ \mathbf{X}_U \end{pmatrix} = \begin{pmatrix} \mathbf{I} - \mathbf{A}_{JJ} - \mathbf{A}_{UJ} - \mathbf{A}_{RJ} & 0 \\ 0 & \mathbf{I} - \mathbf{A}_{JU} - \mathbf{A}_{UU} - \mathbf{A}_{RU} \end{pmatrix}^{-1} \times \begin{pmatrix} \mathbf{F}_{JJ} + \mathbf{F}_{UJ} + \mathbf{F}_{RJ} \\ \mathbf{F}_{JU} + \mathbf{F}_{UU} + \mathbf{F}_{RU} \end{pmatrix}. \tag{4}$$

## 4. Analysis, 1: national totals

Our aggregate results are shown in Table 1. Bilateral trade between the US and Japan reduced US emissions by 14.6 million tons, or 0.35% of US base case emissions. At the same time, bilateral trade increased emissions in Japan by 6.7 million tons, or 0.64% of Japan's base case emissions. There is thus a net global emissions reduction of 7.9 million tons attributable to US–Japan trade, as well as a displacement of emissions from the US onto Japan.

Much larger changes in emissions are associated with worldwide trade, for both countries. The scenario 2 results show that worldwide trade decreases US emissions by 181.6 million tons, or 4.41% of the base case. Similarly, worldwide trade decreases emissions in Japan by 31.7 million tons, or 3.01% of the base case. For the US, trade with the world excluding Japan (the difference between scenarios 1 and 2) reduces emissions by 167.0 million tons, or 4.06% of the base case. For Japan, the comparable figure is a reduction of 38.4 million tons, or 3.65% of the base case. In effect, both the US and Japan have displaced roughly 4% of their industrial carbon emissions on to the rest of the world.

We cannot calculate the corresponding global change in emissions due to trade with other countries, since we have not modeled the change in the rest of the world's emissions under scenario 2. One ambitious attempt to calculate the emissions actually embodied in imports, using data that are not entirely comparable to ours, estimated that US net imports of carbon in 1995 were 263 million tons of $CO_2$, while Japan was a net importer of 187 million tons (Ahmad and Wyckoff, 2003). In these estimates, unlike ours, Japan appears to be a net importer of a much larger percentage of domestic emissions than the US. This is not surprising: Japan's imports come almost exclusively from countries with carbon intensity greater than Japan, including a large share from China and other developing countries. In contrast, US imports include a large volume from other developed countries with carbon intensity similar to or lower than the US, as well as imports from developing countries with greater carbon intensity. Thus the conversion from our estimates for scenario 2 (representing the domestic emissions avoided by imports) to calculation of the true carbon content of imports would be expected to

Table 1
Industrial emissions: base case and scenarios

| | Base case | Change from base case in: | |
|---|---|---|---|
| | | Scenario 1 | Scenario 2 |
| *US* | 4117.4 | 14.6 | 181.6 |
| Percent of base case | | 0.35% | 4.41% |
| *Japan* | 1052.0 | −6.7 | 31.7 |
| Percent of base case | | −0.64% | 3.01% |

Million tons of $CO_2$ equivalent, except percentages.

"inflate" net carbon imports by proportionately much more in Japan than in the US.

## 5. Explaining national differences in carbon intensity

By any measure, the US has a more carbon-intensive economy than Japan. In our model, the US averages 809 kg of $CO_2$ emissions/1000 dollars of shipments, while the corresponding average in Japan is 371.[3] That is, industry as a whole is more than twice as carbon-intensive in the US as in Japan. Among the 165 sectors with nonzero carbon coefficients in both countries, there were only two with greater induced emissions intensity in Japan than in the US: crude petroleum and city water supply. At the other extreme, 10 sectors, four of them related to transportation, had induced carbon intensities more than five times as great in the US as in Japan: road passenger transport, other transport services, car leases, railroads, barber and beauty shops, fruits, real estate, other public services, thermal energy supply and other sanitary services, and aluminum and rolled aluminum products.

There are several reasons why the US is more carbon-intensive. Carbon intensity largely results from energy intensity, and energy is much cheaper in the US, due to abundant natural resources and low energy taxes. Gasoline prices are frequently twice as high in Japan as in the US, due in part to the higher tax on gasoline in Japan ($0.51 versus $0.10/l).[4] Electricity costs more than three times as much per kilowatt hour in Japan as in the US for industrial users, and almost three times as much for residential users.[5]

Not only current prices, but also the long history of low energy prices and abundant, secure energy supplies in the US, compared to the very different history in Japan, has led to the divergent development of the two countries' industries and technologies. Low energy costs in the US have facilitated urban and industrial sprawl, with low-density, decentralized patterns of residence and employment. This pattern locks in high transportation energy requirements, as average travel distances are long and densities on many routes are too low to justify mass transit. Moreover, the extremes of weather in many parts of the US lead to higher energy requirements for heating and cooling.

Japan, in contrast, has a long history of dependence on imports for virtually all energy supplies, which has inevitably favored energy-saving patterns of development. The country's geography has favored high-density settlement and heavily used transportation corridors which are well-suited to mass transit. The moderate climate throughout much of the country has led to low space heating and cooling requirements, at least by American standards.

## 6. Analysis, 2: sectoral emissions and trade

In addition to analyzing the national totals, we examined the pattern of emissions by sector, asking how emissions relate to success in trade. The familiar theory of comparative advantage suggests that each country will specialize in the production of goods for which its production costs are relatively lower, and that such a pattern of specialization maximizes aggregate welfare. Similarly, if each country specialized in the production of goods for which its emissions intensity is lower, aggregate emissions would be minimized. However, the parallel is far from complete. Carbon emissions were unregulated and costless in both countries in 1995, so there was no economic incentive for minimization of emissions.

Plausible a priori theories are available to explain either positive or negative relationships between comparative advantage and emissions intensity. On the one hand, energy efficiency reduces costs for fuel inputs, lowering carbon emissions and production costs at the same time; this suggests that comparative advantage could be negatively correlated with emissions intensity, as in the analysis of Japan–Canada trade cited above. On the other hand, the ability to emit carbon dioxide without costs might be a valuable, free resource which could be substituted for other, costly resources; this could account for a positive correlation between comparative advantage and emissions, as apparently occurs in US–China trade.

US and Japanese emissions intensities by sector are strongly but not perfectly correlated. Define

$\mathbf{I}_J^j$ = induced emissions of sector $j$/value of shipments of sector $j$ in Japan, and

$\mathbf{I}_U^j$ = the corresponding ratio for the US.

For the 165 sectors with emissions coefficients, a simple regression (with $t$ statistics in parentheses below coefficients) finds that

$$\ln(\mathbf{I}_U^j) = \underset{(8.7)}{1.92} + \underset{(20.1)}{0.808}\ \ln(\mathbf{I}_J^j), \text{ or equivalently} \tag{5}$$

$$\mathbf{I}_U^j = 6.83\mathbf{I}_J^{j0.808} \quad (\text{adjusted } r^2 = 0.71)\,. \tag{6}$$

Logarithms are used to reduce the influence of outliers; the emissions intensities in our data set vary by more than two orders of magnitude.[6] The regression coefficient of 0.808 is significantly less than 1, implying that the variance of induced emissions intensity by sector is larger in Japan than in the US.

Is emissions intensity positively or negatively correlated with comparative advantage in bilateral trade? To answer this question, we added a second explanatory variable, representing the balance of trade between the US and Japan, and narrowed the focus to the sectors that are

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[3] These are the unweighted averages of the sectoral carbon intensities, for the 165 I–O sectors with non-zero carbon coefficients in both countries.

[4] E.g. in December 2005, regular unleaded gasoline sold for $1.145/l in Japan, but only half that much, $.575, in the US. http://library.iea.org/Textbase/stats/surveys/mps.pdf.

[5] http://www.eia.doe.gov/emeu/international/electric.html#Prices.

[6] When the regressions reported in this section are run with unlogged intensities, the results clearly suffer from heteroskedasticity (non-normal distribution of residuals); with logarithms of intensities, the residuals are approximately normally distributed.

significant in both economies, and directly engaged in bilateral merchandise trade.

Define
$\mathrm{Ex}^j_J$ = Japan's exports to the US in sector $j$, and conversely for $\mathrm{Ex}^j_U$ ,
$\mathbf{B}^j = (\mathrm{Ex}^j_U - \mathrm{Ex}^j_J)/(\mathrm{Ex}^j_U + \mathrm{Ex}^j_J)$.

That is, $\mathbf{B}^j$ is the US trade surplus or deficit with Japan in sector $j$, as a fraction of the total bilateral trade in the sector. It ranges from $+1$, if the only bilateral trade consists of US exports, to $-1$, if the only bilateral trade is US imports.

Of the 170 sectors in our model, 119 are primary and secondary industries that produce tradable goods, including mining, agriculture, forestry, fishing, and manufacturing. The remainder are tertiary (service) sectors, most of which are not traded. Among the 119 primary and secondary sectors, there are 110 in which there is trade between the US and Japan, and both countries have industries of significant size–defined here as total shipments of more than \$1 billion.[7]

For these 110 sectors, the simple relationship between emissions intensity in the US and Japan is not significantly different from Eq. (5):

$$\ln(\mathbf{I}^j_U) = \underset{(6.4)}{1.66} + \underset{(18.6)}{0.852}\ln(\mathbf{I}^j_J), \text{ with adjusted } r^2 = 0.76. \tag{7}$$

The trade balance alone is weakly related to US emissions intensity, although the relationship just misses the standard test for significance ($p = .064$):

$$\ln(\mathbf{I}^j_U) = \underset{(110.7)}{6.46} + \underset{(1.9)}{0.153}\mathbf{B}^j, \quad \text{with adjusted } r^2 = 0.022. \tag{8}$$

(Since the trade balance takes on negative as well as positive values, its logarithm cannot be used.) Eq. (8) shows that on average, US carbon intensity is slightly greater in sectors where the US has a larger trade surplus (or smaller deficit), although most of the variance in carbon intensity is unrelated to the trade balance.

When the two variables are combined, the US balance of trade remains positively correlated with US carbon intensity:

$$\ln(\mathbf{I}^j_U) = \underset{(6.7)}{1.69} + \underset{(18.8)}{0.844}\ \ln(\mathbf{I}^j_J) + \underset{(2.5)}{0.099}\mathbf{B}^j \text{ with adjusted } r^2 = 0.77. \tag{9}$$

Eq. (9) shows that when controlling for Japan's emission intensity in the same sector, US emissions intensity has a small, significantly positive relationship with the US trade surplus ($p = .014$ for the hypothesis that the trade variable coefficient in (5) is zero).

## 7. Explaining sectoral differences in carbon intensity

As demonstrated in Eq. (9), carbon intensity is positively correlated with success in trade between the US and Japan. If all else is equal, emitting more carbon dioxide is associated with comparative advantage. There are real economic and environmental factors that can account for this correlation, as well as a potentially misleading aspect of the data that may amplify the effect.

The "real" explanation can be clarified by considering a comparative question: Why is the sectoral pattern of Japan–US trade so different from Japan–Canada trade? Since Japan–Canada trade reduces emissions in both countries, an analysis similar to Eq. (9) would presumably find a negative coefficient on the balance of trade variable. In comparison to Japan, both the US and Canada appear to be countries of abundant natural resources, exporting numerous resource-based products. Yet on closer examination, Canada's specialization in this direction is much more complete and, in a sense, more successful. Canada's proportionately greater resource abundance, including the crucial factor of extensive hydroelectric capacity, allows the minimization of carbon emissions in resource-based, energy-intensive exports.

In contrast, US exports to Japan include both resource-based, especially agricultural, products, and assorted manufactured goods such as aircraft, chemicals, and selected categories of electronics and machinery. With a less extreme comparative advantage in natural resources than Canada, but with greater market based advantages such as economies of scale, US trade specialization is less firmly attached to its natural resource base. The historically low price and reliable supply of energy, along with the complete absence of carbon taxes or other limits on emissions, have made it easy for the US to specialize in carbon-intensive activities.

Similarly, Japan's successful export industries have developed in an economy with price incentives for energy efficiency, but no penalties or limits on carbon emission per se. Naturally, Japan's leading exports, such as automobiles, machinery, and electronics, have not come from the most resource-intensive industries; but within their industries, they have used energy and emitted carbon without regulatory constraints. Thus Japan's comparative advantage, relative to the US, is only weakly correlated with sectoral energy and carbon efficiency. In automobile production, Japan's industry with by far the largest exports to the US, the gap in carbon emission intensity between the two countries is barely greater than the overall industrial average.

The comparison of emissions intensity in the US and Japan could also be misleading, in cases where the two countries' prices for the same good are substantially different. Paradoxically, economic *inefficiency* could create the appearance of environmental efficiency, as higher prices imply lower emissions per dollar of sales. For example, our model finds that the electricity sector is 4.2 times more carbon-intensive in the US, meaning that carbon emissions per thousand dollars of electricity sales are 4.2 times as

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[7] The threshold of \$1 billion is a plausible standard for small industries in both countries: the average value of shipments in the 119 primary and secondary sectors was \$30.6 billion for the US, and \$24.5 billion for Japan.

large in the US as in Japan. But as mentioned earlier, electricity costs about three times as much per kilowatt-hour in Japan as in the US. So carbon emissions per kilowatt-hour are only about 1.4 times larger in the US.

The same effect could be at work in sectors such as fruits and poultry farming, where the US has a clear comparative advantage in trade, but much higher emissions per thousand dollars than Japan. If prices per kilogram of fruit or poultry are much higher in Japan, then reported emissions per thousand dollars will be correspondingly lower. Calculation of comparable price indices for each sector in the US and Japan (a challenging task in industries with heterogeneous outputs) would be required to measure the importance of this potential source of spurious correlation. However, for nonperishable traded goods—in other words, the great majority of products in our model—the openness of both countries to world trade should lead to similar prices. Thus it seems unlikely that the perverse statistical effect of economic inefficiency accounts for most of the correlation between carbon intensity and comparative advantage.

## 8. Conclusion and policy implications

We began our research by asking whether US–Japan trade increases or decreases global emissions, and whether one country displaces part of its environmental load onto the other. The answer, as shown by Table 1, is that US–Japan trade decreases global carbon emissions, and shifts part of the carbon burden associated with US consumption onto Japan. In both cases, though, the amounts involved are very small. US exports to Japan are more carbon-intensive, per unit, but US imports from Japan are much larger in volume. These two opposing forces are almost in balance with each other, minimizing the net impact of bilateral trade. In trade with the rest of the world, both countries are substantial net importers of embodied carbon, displacing part of their environmental load onto other countries.

Another way to measure the effects of trade is to compare the emissions embodied in trade with the targets for reduction set by the Kyoto Protocol: 6% reduction from 1990 emissions for Japan, and 7% reduction from 1990 for the US. Since emissions have continued growing since 1990 in both countries, a larger reduction is now required to meet those targets. (Although the US government has not ratified the Kyoto Protocol, the Kyoto target for the US still provides a useful benchmark.) The reductions required to meet the Kyoto targets are compared to our model estimates in Table 2. The comparison is somewhat unfair to our model, both because the model does not encompass all of each country's emissions, and because it is based on 1995, rather than more recent, emissions. Since trade has continued to grow, the same techniques applied to more recent data would estimate a larger quantity of emissions embodied in trade.

The net carbon emissions embodied in bilateral US–Japan trade (base case minus scenario 1) appear small when compared with the reductions required to meet the Kyoto targets. If Japan were credited with the 7 million tons of its emissions attributable to trade with the US, it would amount to a 3% step toward meeting Japan's Kyoto target. If the US were made responsible for the 15 million tons of carbon it avoided through trade with Japan, it would amount to a 1% step away from meeting the US Kyoto target.

Table 2
Carbon embodied in trade vs. total emissions and Kyoto targets

| | Japan | US |
|---|---|---|
| Total emissions, 1990 | 1187 | 6083 |
| Total emissions, 2003 | 1339 | 6894 |
| *Kyoto Protocol targets* | | |
| total emissions, 2008–2012 | 1116 | 5657 |
| change from 1990 levels | −71 | −426 |
| (A) change from 2003 levels | −223 | −1237 |
| *Net $CO_2$ emissions embodied in trade* | | |
| (B) bilateral US–Japan trade | −7 | +15 |
| (C) global trade | +32 | +181 |
| *Trade emissions as % of (Kyoto target: change from 2003)* | | |
| Bilateral US-Japan trade ( = (B)/(A) ) | 3% | −1% |
| global trade ( = (C)/(A) ) | −14% | −15% |

Million tons of $CO_2$ equivalent, except percentages.
*Source*: Total emissions and Kyoto targets from UNFCCC web site.

The net carbon emissions embodied in the global trade of both Japan and the US (base case minus scenario 2) are more significant when measured by the Kyoto standard. Japan's net imports of 32 million tons of $CO_2$ embodied in global trade would add 14% to the reduction required by the Kyoto Protocol. For the US, the net imports of 181 million tons of $CO_2$ embodied in global trade would add 15% to the reduction required by Kyoto.[8] These are noticeable changes, as important as many of the energy and greenhouse gas policies that are currently being debated. They demonstrate that assigning responsibility for pollution based on consumption, rather than production, would increase the share of the climate problem attributable to the richest countries. In the case of greenhouse gases, globalization shifts but does not necessarily reduce the worldwide burden of emissions.

Our sectoral analysis finds a strong but not perfect correlation between emissions intensity in the US and Japan. US industry is on average more than twice as carbon-intensive as its Japanese counterparts, and the distribution of sectoral emissions intensities around those averages looks quite similar in the two countries. There is, in addition, a small but significant correlation between

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[8] Note that our estimates are based on the emissions that would result if the goods that are currently imported were produced domestically in Japan or the US. Since the actual production of imports is often more energy and carbon intensive than American or (especially) Japanese industry, the true worldwide emissions attributable to US and Japanese imports undoubtedly exceed our estimates. See the discussion of the OECD study (Ahmad and Wyckoff, 2003), in the text above.

comparative advantage in bilateral trade and carbon intensity: all else being equal, the sectors that emit more carbon per thousand dollars of sales are more likely to be successful exporters. This could be a reflection of the nature of the two economies and the long-standing absence of any prices or disincentives for carbon emissions. It might also, in part, be a distorted reflection of price differences between the two countries in some sectors, since higher prices per physical unit, with the same technology, imply lower carbon emissions per thousand dollars of sales.

One important policy message, in terms of opportunities for emission reduction, is that many sectors of US industry could benefit from studying Japanese techniques for production with lower carbon emissions. It is no longer credible to claim, in US debates, that significant emission reduction is impossible, when the world's second-largest industrial economy is so far ahead in this respect. If US industrial emissions could be cut to less than half of their present level by adopting Japanese technology, the effect on global carbon emissions and climate change would be immense.

From the perspective of public policy, the study underscores the importance of carbon taxes and other limitations on emissions. In the absence of carbon taxes or other regulations, the US economy has naturally continued to rely on its long-standing experience and comparative advantage in energy-using, carbon-intensive production. Japan is on average much less energy-intensive and carbon-intensive than the US, but the absence (before the Kyoto Protocol) of carbon taxes or regulations has meant that Japan's comparative advantage in trade is not always concentrated in the lowest-emission sectors. As long as energy is cheap and emissions are free, energy-intensive production can be a commercially profitable strategy. National and global policies that raise the costs of energy use and carbon emissions will be required in order to make a more sustainable, low emission path attractive for industry in the US, Japan, and elsewhere.

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