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Consumption-based accounting and the trade-carbon emissions nexus

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ABSTRACT

This paper considers a recently developed consumption-based carbon emissions database from which emissions calculations are made based on the domestic use of fossil fuels plus the embodied emissions from imports minus exports, to test directly for the importance of trade in national emissions. Comparing such consumption-based emissions data to conventionally-measured territory-based emissions data produces several useful conclusions. For example, most countries are net importers of carbon emissions—their consumption-based emissions are higher than their territory-based emissions. Also, while low and high income countries tend to have the largest ratios (of consumption-based emissions to territory-based emissions), the majority of middle-income countries have ratios greater than one as well. Furthermore, China alone is responsible for over half the global outflows of carbon via trade. The econometric estimations—which were robust across income levels—determined that: (i) trade was significant for consumption-based emissions but not for territory-based emissions; (ii) exports and imports offset each other so that exports lower consumption-based emissions, whereas imports increase them; and (iii) the fossil fuel content of a country's energy mix is more important (likely significantly so) for territory-based emissions than for consumption-based emissions; and (iv) domestic fossil fuel prices (oil, gasoline) had a negative impact on territory-based emissions but were insignificant for consumption-based emissions. Hence, there is a wedge between (i) the emissions a country is responsible for—consumption-based emissions—and (ii) the emissions that a country's domestic policies affect—territory-based emissions. So, countries should have both an interest and a responsibility to help lower the carbon intensity of energy in countries that are particularly important for global carbon transfers—China and India.

1. Introduction

There has long been a concern that countries—particularly wealthy ones—might lower emissions via international trade in such a way that those emissions reductions are (at least) offset by increases elsewhere—i.e., in the territory(ies) where the traded goods/services originate (e.g., Rothman, 1998). Recently, a consumption-based carbon emissions database has been developed (Peters et al., 2011)[1] from which emissions calculations are made based on the domestic use of fossil fuels plus the embodied emissions from imports minus exports.[2] Hence, one can now test directly for the importance of trade in national emissions; yet, most economic-based inquiries into the trade-emissions relationship still employ conventionally-measured territory-based carbon data (e.g., Shahbaz et al., 2017). This paper compares and analyzes both consumption- and territory-based carbon emissions data to establish some stylized facts and to estimate relationships among emissions, trade flows, income, and energy structure. The remainder of the paper follows this format: (i) a brief literature review of the early trade and environment work, as well as recent papers using (or not using) consumption-based emissions data; (ii) an initial comparison of consumption-based vs. territory-based carbon emissions; (iii) description of the other data considered and methods employed; (iv) results and discussion of estimations using the two emissions aggregations; and (v) conclusions and policy and modeling lessons.

2. Brief literature review of trade and emissions and recent work employing consumption-based carbon emissions data

Whether the global trade system would facilitate the re-location of pollution-intensive industries to countries with less concern for environmental quality has been a popular topic in environmental economics. The literature has developed in two somewhat distinct strands: mostly theoretical models and mostly empirical analyses. The theoretical literature has tended to support a finding of the migration of polluting industries (either through trade or capital flight) from a country that has introduced a pollution policy (e.g., Chichilnisky, 1994; Copeland and Taylor, 1994, 1995). By contrast, the empirical literature produced more ambiguous results. For example, Tobey (1990), Grossman and Krueger (1993), Jaffe et al. (1995), and Frankel and

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[1] Eora (Lenzen et al., 2013) is a database similar in scale and scope to Peters et al. (2011).

[2] Exactly how best to adjust emissions for consumption and production is neither uncontroversial nor inconsequential (e.g., Kanemoto et al., 2012; Kander et al., 2015; Su and Ang, 2011), but is a topic outside of the scope of the present paper.

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Rose (2005) rejected the so-called "pollution haven" hypothesis, by finding, for example, that factor endowments were more important than pollution tolerance in determining trade patterns and plant location decisions. Meanwhile, Birdsall and Wheeler (1992), Low and Yeats (1992), Lucas et al. (1992), Lee and Ronland-Holst (1997), and Grether and De Melo (2003) determined that openness to trade in developing countries led to specialization or an increase in pollution-intensive production there. The recent literature review in Shahbaz et al. (2017) suggests that the ambiguity among the empirical studies remains. Yet, as mentioned above, the recent development of a consumption-based carbon emissions dataset creates the potential to substantially advance the trade-emissions literature.

However, several of the papers employing the consumption-based carbon emissions data have been mostly descriptive in nature (e.g., Peters et al., 2011, 2012; Steinberger et al., 2012). Other studies that have employed both consumption-based data and regression analysis have not considered trade variables as drivers of those consumption-based emissions (e.g., Jorgenson et al., 2016; Jorgenson and Clark, 2016). Again, the recent trade-focused, environmental economics literature has maintained the use of the territory-based emissions data only (e.g., Aklin, 2016; Shahbaz et al., 2017). Moreover, Shahbaz et al. (2017) did not distinguish between the effects of imports and exports, and Aklin (2016) appears to focus on imports only.

The only papers we know of that have (i) compared estimations made with consumption-based emissions to estimations made with territorial-based emissions and (ii) considered trade variables are Knight and Schor (2014) and Lamb et al. (2014); however, neither of those two papers addressed the importance of the carbon intensity of the energy system nor the role of energy prices. Furthermore, the former paper analyzed high income countries only and did so by considering a short-run model (i.e., the data were first-differenced after converting to natural logarithms), and the latter paper was purely cross-sectional (only data from 2008 was used) and did not consider imports (only exports/GDP was analyzed).

3. Initial look at consumption-based vs. territory-based carbon emissions

Consumption-based carbon emissions in million tonnes of carbon per year cover 117 countries over 1990–2013 and are updated from Peters et al. (2011).[3] These emissions data can be compared to territory-based carbon emissions (also in million tonnes of carbon per year and for the same countries and time-frame) from UNFCCC (2015) and Boden et al. (2015). By comparing these two datasets (i.e., consumption-based vs. territory-based) we can create two additional series: (i) the ratio of consumption-based to territory-based emissions; and (ii) the difference between territory-based and consumption-based emissions, or the net emissions flow.

If the consumption-to-territory emissions ratio is greater than one, then a country effectively imports carbon emissions. Only 28 countries had a mean ratio (over 1990–2013) of less than one. The average country mean ratio was 1.26, and the mean ratio for each year ranged from 1.2 to 1.4. For most countries, the annual ratio was stable: most countries' maximum and minimum yearly ratio was within 20–30% of their mean ratio. So, the vast majority of countries consume more carbon emissions than they produce/emit at home, and the "average" country consumes about one-quarter more carbon emissions.

Fig. 1 displays the mean consumption-to-territory emissions ratio plotted against the mean GDP per capita (in log form). The relationship displays a U-shape: the poorest and richest countries tend to have ratios greater than one; whereas, the countries with ratios less than one tend to be middle-income. However, the majority of middle-income countries have ratios of more than one (roughly 37 of 55 such middle-income countries). Hence, the transfer of carbon is not purely a "South-to-North" or poor-to-rich country phenomenon.

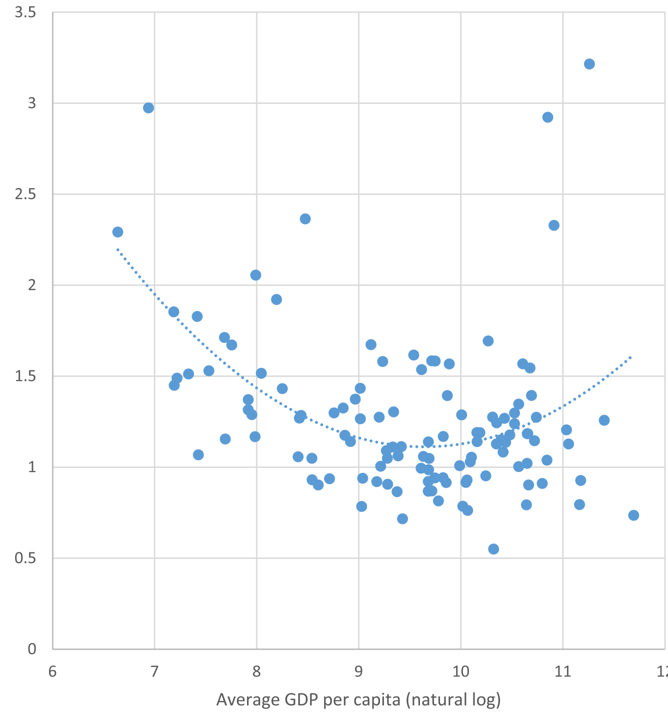

Fig. 1. The yearly average (over 1990–2013) ratio of consumption-based carbon emissions to territory-based carbon emissions is plotted against the yearly average GDP per capita (in natural log form) for 117 countries. A polynomial, U-shaped trend line is shown (which produced an R-squared of 0.22). Emissions data are updated from Peters et al. (2011). GDP per capita data from World Bank World Development Indicators.

Of the 28 countries with a mean consumption-to-territory emissions ratio of less than one, fuel exports make up at least 75% of total exports for 12 of them. Yet, other than a reliance on fuel exports, export orientation does not appear to have a strong impact on the ratio. Only eight countries with exports contributing to greater than 50% of GDP had a ratio of less than one, and seven countries with imports comprising at least 75% of GDP had a ratio of less than one.

As Fig. 2 displays, there is a slight positive (and exponential) relationship between the mean consumption-to-territory emissions ratio and the mean import-to-exports ratio. So, the more imports exceed exports, the more consumption-based emissions exceed territory-based ones.

One important exception to the general stability of net emissions transfers is highlighted by the admission of China into the World Trade Organization (WTO).[4] Indeed, since 2005 China is responsible for over half of global net carbon emissions transfers. Further, China and four other countries—Russia, India, South Africa, and Ukraine—have been responsible for 65%–86% of yearly net carbon outflows over 1990–2013, as displayed in Fig. 3. The importance of China and India (which passed Russia as the second largest source of net emissions flows) for global carbon transfers reflects a combination of (i) the scale of their economies and (ii) the carbon intensity of their energy systems, rather than trade or industry share of GDP. For example, over 2002–2013, exports made up less than 30% of China's GDP on average, and industry made up a relatively small share of GDP in India (about one-quarter). Moreover, according to data from Peters et al. (2011), of the top 10 sectors in terms of average yearly carbon flows over 1990–2008 for China, only four sectors are classified as energy-intensive, and those four sectors account for less than 40% of China's average yearly net carbon flows.

[3] That data is accessed via: http://www.globalcarbonproject.org/carbonbudget/16/data.htm.

[4] China became a member of the WTO on December 11, 2001.

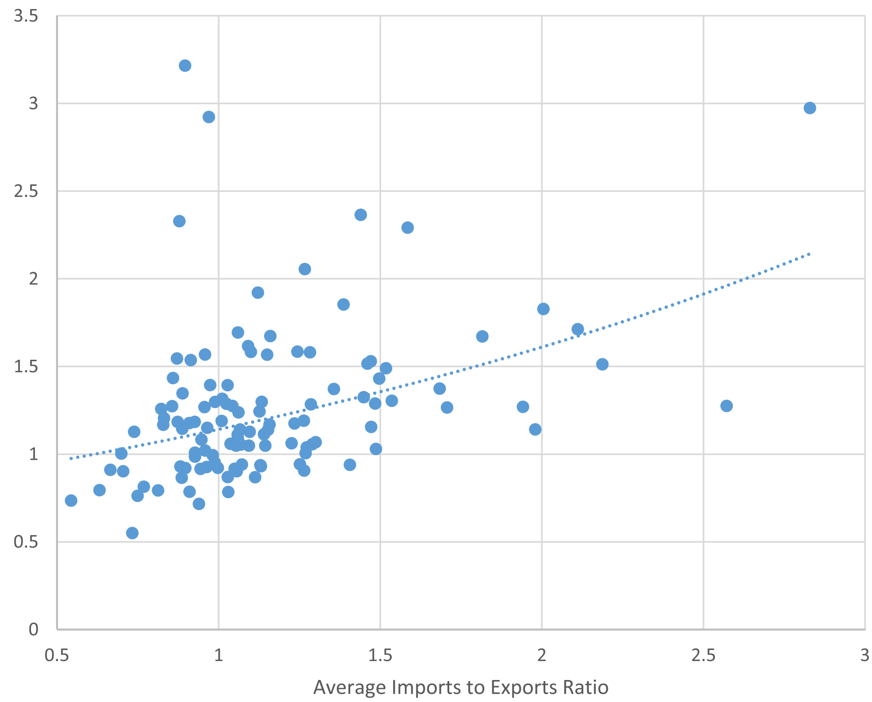

Fig. 2. The yearly average (over 1990–2013) ratio of consumption-based carbon emissions to territory-based carbon emissions is plotted against the yearly average imports to exports ratio (in share of GDP) for 117 countries. Also displayed is an exponential trend line: $y = 0.81e^{0.34x}$ (R-squared of 0.18). Emissions data are updated from Peters et al. (2011). Imports and exports data from World Bank World Development Indicators.

4. Additional data, methods, models, and hypotheses

Other variables sourced from the World Bank's World Development Indicators include: real GDP per capita (adjusted for PPP and in 2011 international USD); population (to convert emissions to per capita); fossil fuel energy consumption as a share of total energy consumption; and industry value added, trade, exports of goods and services, and imports of goods and services, all as a percent of GDP. Because of missing data, ultimately an unbalanced panel consisting of 102 countries and spanning 1990–2013 is created.

In addition, from the International Energy Agencies' energy prices series, a real index of total energy prices for industry and households and a real index of oil products prices for industry and households are assembled for a group of 29 and a group of 33 OECD countries, respectively. Also, a real index of retail gasoline prices is constructed from the Asian Development Bank's Statistical Database System and the

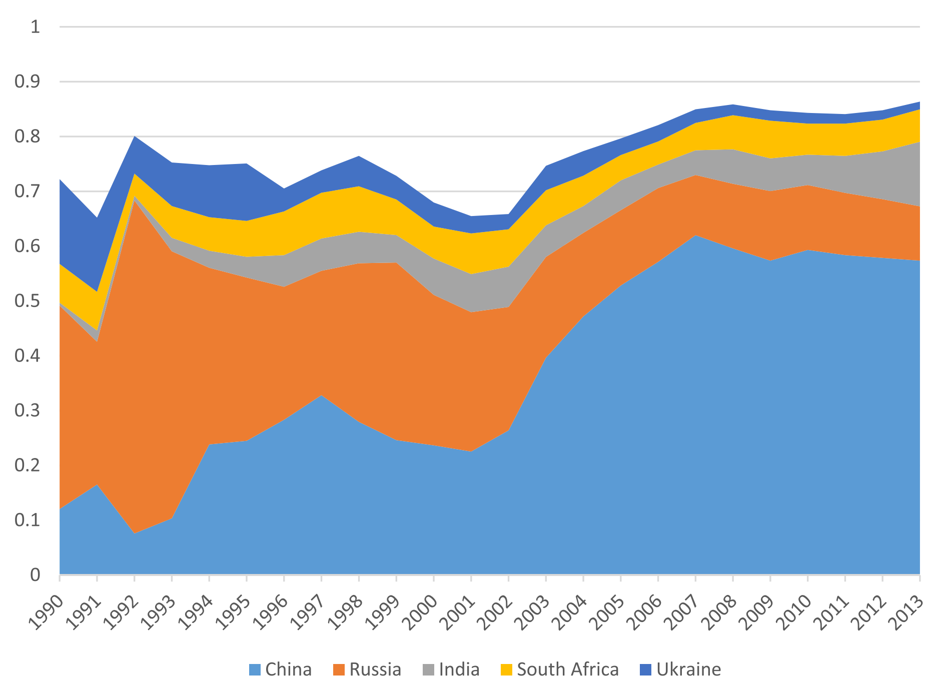

Fig. 3. The share of net global carbon emissions flows for five countries. Data are updated from Peters et al. (2011).

International Energy Agency's Energy Prices and Taxes series (which was discontinued for non-OECD countries in 2012 and contained data for only a few such countries). The gasoline index consists of data from 33 OECD countries and 16 non-OECD countries.[5] For the countries included, gasoline prices were highly correlated with diesel prices (ρ-value = 0.9 and higher); so, inferences/findings should be valid for countries that have a large proportion of diesel vehicles.

Given earlier work (e.g., Liddle, 2015; Shahbaz et al., 2017) and the importance of the world trade system, we expect the data to exhibit both cross-sectional correlation and nonstationarity. Indeed, the Pesaran (2004) CD test,[6] which employs the correlation coefficients between the time-series for each panel member, rejected the null hypothesis of cross-sectional independence for each variable considered. Furthermore, the absolute value mean correlation coefficients ranged from 0.4 to 0.9 (Table 1). The Pesaran (2007) panel unit root test for heterogeneous panels allows for cross-sectional dependence to be caused by a single (unobserved) common factor.[7] The results of that test—shown in Table 2—suggest that the variables are nonstationary in levels. Lags of the dependent variable are used to control for serial correlation. The model includes individual constants and time trends.

In addition to both cross-sectional correlation and nonstationarity, we expect the data to reveal heterogeneity. Thus, we employ a heterogeneous panel estimator that addresses both nonstationarity and cross-sectional dependence, i.e., the Pesaran (2006) common correlated effects mean group estimator (CMG).[8] The CMG estimator accounts for the presence of unobserved common factors by including in the regression cross-sectional averages of the dependent and independent variables. The CMG estimator is robust to nonstationarity, cointegration, breaks, and serial correlation.

Previous work (e.g., Shahbaz et al., 2017) has included both GDP per capita (GDP) and trade openness. We further divide trade into export and import shares of GDP (EX, IM, respectively). Since carbon models sometimes include a measure of economic structure (e.g., Aklin, 2016), we test for the significance of industry share of GDP in an initial regression. Clearly, carbon intensity of the energy system or fossil fuel's share of energy consumption (FFsh) should impact carbon emissions (e.g., Liddle, 2015). Lastly, because prices are often suggested as policy responses to climate change, we consider several energy price indices.

Thus, for per capita carbon emissions (CO), both territory-based (t) and consumption-based (c), our main regression model (i.e., largest sample, only significant variables) is:

$$\mathrm{CO}_{it}^{c,t} = \beta_i^1 \mathrm{GDP}_{it} + \beta_i^2 \mathrm{FFsh}_{it} + \beta_i^3 \mathrm{EX}_{it} + \beta_i^4 \mathrm{IM}_{it} + \alpha_i + Z_{it} + \varepsilon_{it} \tag{1}$$

where the βs are cross-sectional specific coefficients to be estimated, α is a cross-sectional specific constant, ε is the error term, and Z represents the cross-sectional average terms. Those cross-sectional average terms are displayed in Eq. (2) below:

$$Z_{it} = \rho_i^1 \overline{\mathrm{CO}_t^{c,t}} + \rho_i^2 \overline{\mathrm{GDP}_t} + \rho_i^3 \overline{\mathrm{FFsh}_t} + \rho_i^4 \overline{\mathrm{EX}_t} + \rho_i^5 \overline{\mathrm{IM}_t} \tag{2}$$

where the bar represents an average over the cross-sections (countries).

Like time dummies, the cross-sectional average terms can account for temporary, global shocks. But cross-sectional dependence also is caused by so-called spillover effects (e.g., international trade) that are much more accurately modeled by cross-sectional averages than merely time dummies/trends. Moreover, these spillover effects are not simply a proximity/geographical phenomenon that could be modeled by a spatial lag (e.g., the previously demonstrated global importance of China for embodied carbon flows).

We expect that income would have a positive relationship with both (territory-based and consumption-based) aggregations of carbon emissions. Exports should lower consumption-based emissions; whereas, imports should increase them. We do not expect trade flows to impact territory-based emissions. The carbon intensity of the energy system should be positively related to both emissions aggregations; however, the impact of the energy system's carbon intensity should be greater for territory-based emissions (since for consumption-based emissions, the characteristic of trading partners' energy systems would matter, too). Prices should impact (negatively) territory-based emissions, but perhaps not impact significantly consumption-based emissions. Also, the fossil fuel-based prices (oil, gasoline) should have a greater impact than a more general energy price (since nonfossil fuel sources would be affected, too).

Table 1
Cross-sectional dependence: absolute value mean correlation coefficients and Pesaran (2004) CD test.

Variables	CD-test	Abs corr. coeff.
Log exports share	90.0**	0.46
Log imports share	94.6**	0.46
Log trade share	92.5**	0.48
Log industry share	22.3**	0.45
Log total fossil fuel share	3.0*	0.52
Log consumption-based CO_2 pc	53.8**	0.42
Log territory-based CO_2 pc	26.7**	0.51
Log GDP pc	267.0**	0.82
Log total energy price index	84.6**	0.86
Log oil price index	85.6**	0.79
Log gasoline price index	99.3*	0.70

Note:
** p-Value 0.001.
* p-Value 0.01.

5. Estimation results and discussion

Table 3 displays the initial regression results for the entire panel (the left-most columns of Table 3). Industry's share of GDP is insignificant for both dependent variables (territory- and consumption-based emissions). Whereas trade's share of GDP is insignificant for territory-based emissions, it is significant for consumption-based emissions. Also, fossil fuels' share in the energy mix, while significant for both emissions aggregations, is substantially higher (and nearly significantly higher at the 95% level) for territory-based emissions than for consumption-based emissions.

Table 2
Pesaran (2007) panel unit root tests.

No. lags	Variables in levels			Variables in first differences		
	0	1	2	0	1	2
Log exports share	0.79	0.20	0.98	0.00	0.00	0.24
Log imports share	0.41	0.01	1.00	0.00	0.00	0.00
Log trade share	0.91	0.18	1.00	0.00	0.00	0.03
Log industry share	0.55	0.16	0.99	0.00	0.00	0.02
Log total fossil fuel share	0.66	0.14	1.00	0.00	0.00	0.01
Log consumption-based CO_2 pc	0.01	0.97	1.00	0.00	0.00	0.02
Log territory-based CO_2 pc	0.40	0.99	1.00	0.00	0.00	0.01
Log GDP pc	1.00	1.00	1.00	0.00	0.00	0.04
Log total energy price index	0.86	0.96	0.98	0.00	0.00	0.61
Log oil price index	0.26	0.96	0.97	0.00	0.00	0.08
Log gasoline price index	0.03	0.85	0.89	0.00	0.00	0.00

Notes: p-Values shown for null hypothesis of I(1). A constant and individual time trend are included.

[5] Those non-OECD countries are China, Cyprus, Hong Kong, Croatia, India, Indonesia, Kazakhstan, Sri Lanka, Malaysia, Nepal, Pakistan, Philippines, Romania, South Africa, Thailand, and Chinese Taipei.

[6] This test is implemented via the STATA command xtcd, which was developed by Markus Eberhardt.

[7] This test is implemented via the STATA command pescadf, which was developed by Piotr Lewandowski.

[8] This estimator is implemented via the STATA command suite xtmg, which was developed by Markus Eberhardt.

Table 3
Trade and carbon emissions. Full panel. Pesaran (2006) CMG estimator.

Dependent variable	Territory-based CO_2 p.c.	Consumption-based CO_2 p.c.	Territory-based CO_2 p.c.	Consumption-based CO_2 p.c.
GDP p.c.	0.57***	0.66***	0.51***	0.53***
	[0.45 0.69]	[0.49 0.83]	[0.38 0.63]	[0.37 0.69]
Trade share	0.01	−0.17***		
	[−0.04 0.06]	[−0.27–0.08]		
Industry share	0.03	0.06		
	[−0.05 0.12]	[−0.07 0.19]		
Fossil fuels share	1.25***	0.76***	1.35***	0.76***
	[0.99 1.51]	[0.49 1.02]	[1.08 1.62]	[0.47 1.06]
Exports share			0.03	−0.32***
			[−0.02 0.09]	[−0.40–0.24]
Imports share			−0.03	0.20***
			[−0.10 0.04]	[0.10 0.29]
Obs	2261	2258	2397	2394
x-Sects	100	100	102	102
CD (p)	2.8 (0.01)	4.3 (0.00)	2.2 (0.03)	4.6 (0.00)

Notes: Statistical significance level of 5%, 1% and 0.1% denoted by *, **, and ***, respectively. 95% confidence intervals in brackets. CD is the test statistic from the Pesaran (2004) CD test; the corresponding p-value is in parentheses. The null hypothesis of the test is cross-sectional independence.

Table 4
Trade and carbon emissions. OECD and Non-OECD panels. Pesaran (2006) CMG estimator.

Dependent variable	OECD		Non-OECD	
	Territory-based CO_2 p.c.	Consumption-based CO_2 p.c.	Territory-based CO_2 p.c.	Consumption-based CO_2 p.c.
GDP p.c.	0.42***	0.57***	0.57***	0.64***
	[0.25 0.59]	[0.35 0.79]	[0.39 0.74]	[0.38 0.89]
Fossil fuels share	1.28***	0.52**	1.21***	0.70***
	[0.73 1.62]	[0.16 0.88]	[0.90 1.52]	[0.37 1.02]
Exports share	0.01	−0.24***	0.02	−0.33***
	[−0.07 0.10]	[−0.32–0.16]	[−0.04 0.08]	[−0.42–0.24]
Imports share	−0.02	0.14*	−0.04	0.22***
	[−0.12 0.08]	[0.01 0.27]	[0.13 0.05]	[0.11 0.33]
Obs	781	781	1616	1613
x-Sects	33	33	69	69
CD (p)	0.4 (0.66)	2.0 (0.04)	0.3 (0.74)	0.5 (0.60)

Notes: Statistical significance level of 5%, 1% and 0.1% denoted by *, **, and ***, respectively. 95% confidence intervals in brackets. CD is the test statistic from the Pesaran (2004) CD test; the corresponding p-value is in parentheses. The null hypothesis of the test is cross-sectional independence.

When trade is split into exports and imports—the main regression of Eq. (2) (and displayed in the right-most columns of Table 3), those flows are insignificant for territory-based emissions, but significant and of opposite signs for consumption-based emissions. Exports tend to lower consumption-based emissions, while imports tend to increase them. (Knight and Schor, 2014, in their OECD-only, short-run analysis, similarly found trade to be insignificant for territory-based emissions and exports and imports to have opposite effects on consumption-based emissions.)

An insignificant effect of trade on territory-based emissions—although contrary to some earlier findings—is reasonable-to-expected in a world without a uniform carbon price. While some energy/electricity intensive sectors do tend to be geographically specialized (e.g., metal smelting, iron and steel), those sectors/processes are not necessarily carbon intensive; indeed, inexpensive renewable energy (hydro and geothermal) has led Canada, Iceland, and Norway to become important aluminum processing centers. And, as discussed earlier, China's and India's roles as major net exporters of embodied carbon reflects their carbon intensive energy systems and not economies skewed toward industry and energy intensive sectors.

Fossil fuels' share of the energy mix is now statistically significantly lower for consumption-based emissions than for territory-based emissions (now their 95% confidence intervals do not overlap). Consumption-based emissions equal territory-based emissions plus the carbon embodied in imports minus the carbon embodied in exports, and, as demonstrated previously, most countries have positive net emissions embodied in trade. So, those additional consumption-based emissions depend on the carbon intensity of trading partners' energy systems, rather than the carbon intensity of ones' own system (which determines territory-based emissions). Lastly, while the residuals have evidence of cross-sectional correlation (the CD statistic is significant), independence cannot be rejected more often than not when the panels are smaller, as will be seen in subsequent tables.[9]

Table 4 splits the sample into OECD and non-OECD countries. The whole-sample results are reinforced, i.e., (i) exports and imports matter for consumption-based emissions only; (ii) exports lower such emissions, whereas imports increase them; and (iii) the fossil fuel content of a country's energy mix is much more important for territory-based emissions than for consumption-based emissions. While the absolute value of several coefficients is larger for the non-OECD country sample than for the OECD sample, by considering the 95% confidence intervals, it does not appear that any of those differences between OECD- and non-OECD-estimations are statistically significant. This lack of difference between OECD and non-OECD countries provided contrast to Liddle (2015), which determined that the GDP per capita elasticity was significantly smaller for OECD countries than for non-OECD countries (that analysis considered conventionally-measured, territory-based carbon emissions). For the smaller samples, cross-sectional independence cannot be rejected in the residuals for most estimations.

Table 5 presents results for the panels that are constructed based on World Bank income classifications. In most cases the previously discussed findings hold. One exception is that, for the lower-middle and upper-middle income panels, the difference in the coefficients for fossil fuels' energy mix share is smaller—and not statistically significant—between the estimates for territory-based and consumption-based emissions.

[9] The Pesaran (2007) panel unit root test confirmed that the regression residuals for all the estimations were I(0) (results not shown).

Table 5
Trade and carbon emissions. World Bank income classification-based panels. Pesaran (2006) CMG estimator.

Dependent variable	Low income: Territory-based CO_2 p.c.	Low income: Consumption-based CO_2 p.c.	Lower-middle income: Territory-based CO_2 p.c.	Lower-middle income: Consumption-based CO_2 p.c.	Upper-middle income: Territory-based CO_2 p.c.	Upper-middle income: Consumption-based CO_2 p.c.	Middle income: Territory-based CO_2 p.c.	Middle income: Consumption-based CO_2 p.c.	High income: Territory-based CO_2 p.c.	High income: Consumption-based CO_2 p.c.
GDP p.c.	0.88*	0.22	0.84***	0.67***	0.52***	0.76***	0.65***	0.81***	0.40***	0.47***
	[0.08 1.69]	[−0.48 0.91]	[0.47 1.21]	[0.36 0.98]	[0.32 0.73]	[0.51 1.01]	[0.46 0.83]	[0.63 0.99]	[0.18 0.63]	[0.19 0.75]
Fossil fuels share	0.46*	0.49**	0.98***	0.70**	1.58***	1.20***	1.22***	0.61***	1.34***	0.51**
	[0.05 0.87]	[0.15 0.83]	[0.52 1.44]	[0.20 1.19]	[1.05 2.11]	[0.60 1.80]	[0.92 1.53]	[0.29 0.94]	[0.90 1.78]	[0.13 0.90]
Exports share	0.27	−0.11	0.02	−0.19**	−0.02	−0.39***	−0.02	−0.33***	0.07	−0.28**
	[−0.04 0.59]	[−0.33 0.11]	[−0.10 0.14]	[−0.31–0.07]	[−0.12 0.08]	[−0.50–0.29]	[−0.09 0.06]	[−0.42–0.24]	[−0.04 0.18]	[−0.45–0.10]
Imports share	−0.06	−0.08	−0.04	0.17*	0.003	0.23*	−0.03	0.20***	−0.04	0.27*
	[−0.36 0.23]	[−0.21 0.04]	[−0.17 0.09]	[0.01 0.33]	[−0.13 0.13]	[0.05 0.41]	[−0.12 0.07]	[0.08 0.32]	[−0.18 0.10]	[0.06 0.49]
Obs	168	168	612	612	802	799	1414	1411	815	815
x-sects	7	7	26	26	34	34	60	60	35	35
CD (p)	−1.8 (0.07)	−2.0 (0.05)	−1.1 (0.27)	−0.8 (0.45)	−0.6 (0.58)	0.7 (0.47)	−0.8 (0.43)	1.9 (0.06)	1.9 (0.06)	2.6 (0.01)

Notes: Statistical significance level of 5%, 1% and 0.1% denoted by *, **, and ***, respectively. 95% confidence intervals in brackets. CD is the test statistic from the Pesaran (2004) CD test; the corresponding p-value is in parentheses. The null hypothesis of the test is cross-sectional independence.

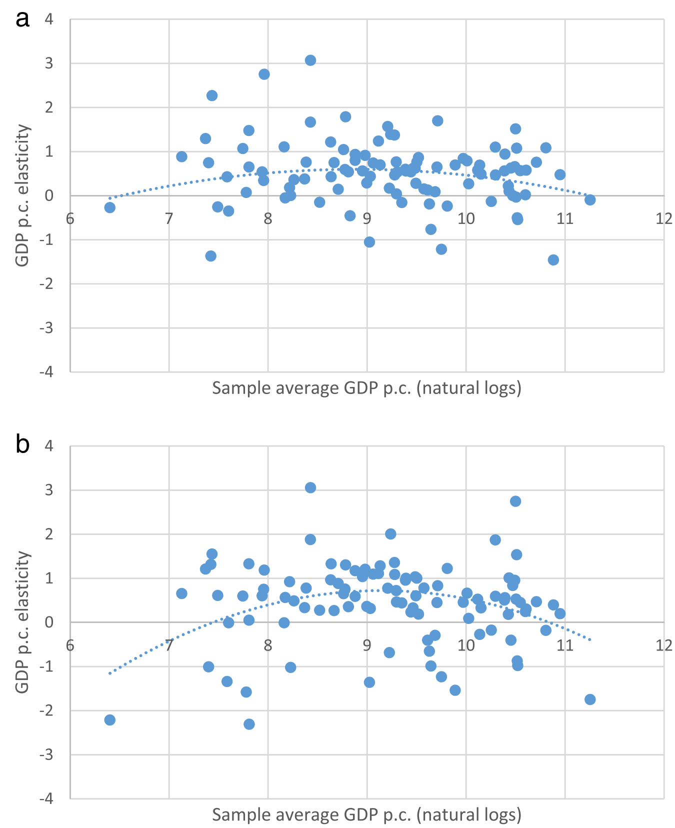

Fig. 4. a & b. Individual country income elasticity estimates and the country average GDP per capita (in natural logarithms) for the sample period (for all countries). Territory-based carbon emissions is the dependent variable for Fig. 4-a (top); consumption-based carbon emissions is the dependent variable for Fig. 4-b (bottom). Also shown are polynomial, inverted-U shaped trend lines (which produced R-squares of 0.02 and 0.05, respectively).

However, if those two panels are combined (to form a 60 country middle income panel), the previous finding holds—that the fossil fuels' energy mix coefficient is substantially, and likely significantly, larger for territory-based emissions than for consumption-based emissions. Over the course of the study period (1990–2013) the distinction between the lower-middle and upper-middle income classifications may not be meaningful for many countries. Lastly, the results for the low income panel are largely insignificant—but this panel consists of only seven countries. Moreover, while low income countries tend to have consumption-to-territory emissions ratios of well above one, they tend to have low per capita emissions (corresponding to their low per capita GDPs).

A common line of inquiry in environmental economics/social science is whether pollution varies nonlinearly with GDP per capita (indeed, there is often overlap between the environment-trade literature and the environment-pollution/environmental Kuznets curve literature). Such nonlinearities are often investigated by estimating emissions as a quadratic function of GDP per capita (e.g., Aklin, 2016; Shahbaz et al., 2017). However, it is incorrect to make a nonlinear transformation of a nonstationary (and potentially cointegrated) variable, like GDP per capita, in ordinary least squares (Muller-Furstenberger and Wagner, 2007; Itkonen, 2012). Furthermore, this polynomial model has been criticized for lacking flexibility (e.g., Lindmark, 2004).

One alternative to the GDP polynomial is to analyze income-based panels to determine whether the estimated elasticities differ across those panels. The results displayed in Table 5 above suggest that for the present case, the relationships do not vary according to income levels. Still another alternative that takes advantage of the heterogeneous nature of the elasticity estimations (i.e., elasticities are estimated for each cross-section) is to plot individual country-specific GDP per capita elasticity estimates against the individual country average GDP

Table 6
Trade and carbon emissions with energy price variables. Pesaran (2006) CMG estimator.

Dependent variable	OECD countries				OECD & non-OECD countries			
	Energy price index		Oil price index		Gasoline price index			
	Territory-based CO_2 p.c.	Consumption-based CO_2 p.c.	Territory-based CO_2 p.c.	Consumption-based CO_2 p.c.	Territory-based CO_2 p.c.	Consumption-based CO_2 p.c.	Territory-based CO_2 p.c.	Consumption-based CO_2 p.c.
GDP p.c.	0.44****	0.84****	0.37****	0.50****	0.41****	0.44****	0.46****	0.59****
	[0.30 0.57]	[0.53 1.16]	[0.20 0.54]	[0.32 0.68]	[0.28 0.53]	[0.24 0.63]	[0.32 0.59]	[0.42 0.76]
Fossil fuels share	1.35****	0.68****	1.39****	0.54***	1.37****	0.68***	1.23****	0.82****
	[0.92 1.78]	[0.29 1.08]	[0.92 1.86]	[0.15 0.93]	[0.95 1.80]	[0.27 1.08]	[0.90 1.56]	[0.40 1.24]
Exports share	0.01	−0.30****	0.01	−0.29***	0.03	−0.26****	0.05	−0.26****
	[−0.06 0.07]	[−0.47–0.13]	[−0.08 0.11]	[−0.48–0.11]	[−0.03 0.10]	[−0.39–0.13]	[−0.03 0.13]	[−0.38–0.14]
Imports share	−0.004	0.19***	0.02	0.16	−0.03	0.21***	−0.03	0.17***
	[−0.13 0.12]	[0.05 0.33]	[−0.08 0.12]	[−0.03 0.34]	[−0.12 0.07]	[0.07 0.35]	[−0.13 0.06]	[0.06 0.29]
Price	−0.03	0.08	−0.09*	−0.06	−0.10**	−0.03	−0.06*	−0.08
	[−0.17 0.10]	[−0.07 0.23]	[−0.19 0.01]	[−0.18 0.06]	[−0.19–0.01]	[−1.29 0.07]	[−0.13 0.000]	[−0.18 0.02]
Obs	695	695	770	770	769	769	1097	1097
x-sects	29	29	33	33	33	33	49	49
CD (p)	−1.7 (0.10)	2.8 (0.00)	0.6 (0.54)	1.6 (0.12)	1.3 (0.18)	2.0 (0.04)	2.2 (0.03)	3.1 (0.00)

Notes: Statistical significance level of 10%, 5%, 1% and 0.1% denoted by *, **, ***, and ****, respectively. 95% confidence intervals in brackets. CD is the test statistic from the Pesaran (2004) CD test; the corresponding p-value is in parentheses. The null hypothesis of the test is cross-sectional independence.

per capita for the whole sample period (as in Liddle, 2015). Those plots are displayed in Fig. 4 a & b (Fig. 4-a for territory-based emissions and Fig. 4-b for consumption-based emissions). The results from Table 5 are reinforced since Fig. 4-a & -b suggest little variation of GDP per capita elasticities by average GDP per capita (while inverted-U trend lines can be fitted, the accompanying R-squares are very small).

Finally, Table 6 displays an analysis that considers three energy price indices (and OECD/mostly OECD country panels). Given the previous results for fossil fuels' share of the energy mix, one might expect energy prices to matter more for territory-based emissions than for consumption-based emissions since the carbon embodied in imports would be influenced by the exporting country's energy prices.

The broad-based energy price index was insignificant for both emissions aggregations. Perhaps, the substantial amount of non-fossil fuel energy in several OECD countries (e.g., nuclear, hydro, wind) causes a disconnect between an aggregate measure of energy prices and carbon emissions. However, the oil price index—which may be correlated with the typically carbon-intensive transport sector—conformed to the above hypothesis. The price variable was insignificant for consumption-based emissions, but significant (at the 10% level) and negative for territory-based emissions. The final four columns of the table display the results for the gasoline price index (which is clearly associated with the transport sector). Now the price effect for the OECD country panel is statistically significant at the standard level and negative for territory-based emissions, and, again insignificant for consumption-based emissions. The results are effectively the same for the combined OECD and non-OECD panel—the p-value for the negative price coefficient in the territory-based emissions regression is 0.051.

6. Conclusions and implications

This paper exploited a recently developed consumption-based carbon emissions database (by Peters et al., 2011) from which emissions calculations are made based on the domestic use of fossil fuels plus the embodied emissions from imports minus exports to test directly for the importance of trade in national emissions. Comparing the consumption-based carbon emissions data to the conventionally-measured territory-based emissions data revealed that most countries are net importers of carbon emissions—their consumption-based emissions are higher than their territory-based emissions. While low and high income countries tend to have the largest ratios (of consumption-based emissions to territory-based emissions), the majority of middle-income countries have ratios greater than one as well. Furthermore, China alone is responsible for over half the global outflows of carbon via trade, and four additional countries (India, Russia, South Africa, and Ukraine) are responsible for a majority of the remaining outflows. The importance of China (and the other four countries) in this international transfer of carbon emissions is about the scale of its (their) economy(ies) and the carbon intensity of its (their) energy system(s), rather than having economic systems skewed toward energy or export intensive goods and services.

The econometric estimations produced credible/easily justified results: (i) trade was significant for consumption-based emissions but not for territory-based emissions; (ii) exports and imports offset each other so that exports lower consumption-based emission, whereas imports increase them; (iii) the fossil fuel content of a country's energy mix is more important (likely significantly so) for territory-based emissions than for consumption-based emissions; and (iv) domestic oil and gasoline price mattered for territory-based emissions but not for consumption-based emissions. Those results were robust across income levels (except for oil price, for which OECD data only was available). Thus, for territory-based emissions, fossil fuel consumption (but not so much trade) matters; and for consumption-based emissions, trade patterns (exports, imports) matter, and trading partners' fossil fuel consumption matters (which, unfortunately, is not in the database).[10]

While exports' share of GDP had a negative coefficient, we cannot live in a world in which every country exports more than it imports. Furthermore, carbon embodied in trade drives a wedge between (i) the emissions that a country's actions/consumption are responsible for—consumption-based emissions—and (ii) the emissions that a country's climate policies (e.g., renewable targets, carbon pricing) affect—territory-based emissions. For example, about 17% of the carbon emissions embodied in the OECD's final demand come from non-OECD countries (via trade).[11] So, a main policy lesson is that countries should have both an interest and a responsibility to help lower the carbon intensity of energy in countries that are particularly important for global carbon transfers—China and India. In other words, consumption-based emissions accounting may be helpful in assessing responsibility for climate change, but mitigation efforts need to be coordinated among countries, and the location of such mitigation investments should be informed by trade flows. Alternatively, in terms of the Paris climate agreement, countries whose consumption-based carbon emissions are greater than their territory-based ones, could establish their nationally determined contributions on those consumption-based emissions (rather than on territory-based emissions). As a final policy implication, the price regressions (Table 6) implied a role for an international carbon price since the coefficient for the price of oil products was (marginally)

[10] At least, not in the database that was accessed/used for this analysis.

[11] Data from OECD.stat, accessed September 19, 2017.

significant and negative for territory-based emissions but insignificant for consumption-based emissions.

Lastly, in terms of future work, clearly, for modelers wanting to investigate further trade's role in carbon emissions, it is important both (i) to consider consumption-based emissions and (ii) to consider imports and exports separately. Also, one could dive deeper into the Input-Output-table-based consumption emissions data (perhaps, considering the Eora database that was mentioned in Footnote 1) to analyze emissions flows among particular countries or flows from specific industries. Lastly, since consumption-based emissions are important for equity considerations and since regulation is often production based/focused, empirical research on the feasibility/desirability of consumption-based regulation needs to be conducted.[12]

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2017.11.004.

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[12] I owe this suggestion to a discussant of a version of this paper.