Will economic restructuring in China reduce trade-embodied CO_2 emissions?*

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Will economic restructuring in China reduce trade-embodied CO_2 emissions?

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ABSTRACT

We calculate carbon dioxide (CO_2) emissions embodied in China's net exports using a multi-regional input–output database. We find that the majority of China's export-embodied CO_2 is associated with production of machinery and equipment rather than energy-intensive products, such as steel and aluminum. In 2007, the largest net recipients of embodied CO_2 emissions from China include the EU (360 million metric tons, mmt), the US (337 mmt) and Japan (109 mmt). Overall, annual CO_2 emissions embodied in China's net exports totaled 1177 mmt, equal to 22% of China's total CO_2 emissions. We also develop a global general equilibrium model with a detailed treatment of energy and CO_2 emissions. We use the model to analyze the impact of a sectoral shift in the Chinese economy away from industry and towards services, both without and with a decrease in China's trade surplus, and a tax on energy-intensive exports, which reflect policy objectives in China's Twelfth Five-Year Plan (2011–2015). We find that without a decrease in the trade surplus, both policies will have a limited impact on China's net exports of embodied CO_2 emissions. The policies have an even smaller effect on global emissions, as reduced production in China is partially offset by increased production elsewhere.

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1. Introduction

China's rapid growth over the last thirty years has brought great benefits but has come at a cost of large increases in energy use and environmental damage. With the rapid growth of its economy and international trade linkages, China has become the world's largest exporter, the second largest importer, and the second largest national economy in the world in value terms (The World Bank, 2012). In 2010, China accounted for 20% of global energy demand (BP, 2012) and surpassed the U.S. to become the world's largest consumer of energy and source of carbon dioxide (CO_2) emissions (International Energy Agency, 2011). A significant amount of China's CO_2 emissions are embodied in goods produced for export.

In recent decades, China has largely benefited from a global trend to relocate labor-intensive manufacturing from developed to developing countries. Given that developing countries generally have less advanced production technologies and fewer environmental restrictions, the shift of manufacturing is often considered tantamount to a transfer of fossil fuel consumption and environmental impact (Copeland and Taylor, 1994, 1995; Muradian et al., 2002; Tang et al., 2012).[1]

Large total and exported quantities of embodied CO_2 emissions in China translate into environmental damages and also make China a target of carbon tariff policies implemented overseas. Developed countries with strict climate policies have discussed imposing tariffs based on the carbon embodied in trade to avoid carbon leakage and to shore up the competitiveness of domestic producers (Bednar-Friedl et al., 2012). As carbon tariffs imposed in OECD (Organization for Economic Cooperation and Development) countries penalize carbon-intensive exporters, non-OECD countries, including China, could potentially suffer substantial welfare losses (Boehringer et al., 2012). One analysis has suggested that China in particular would suffer a GDP loss of 4% as a result of imposing such tariffs (Boehringer et al., 2011). China has grown aware of the vulnerabilities associated with the high energy

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Abbreviations: CGE, computable general equilibrium; SRIO, single-regional input output (analysis); MRIO, multi-regional input output (analysis); FYP, Five-Year Plan (of China).

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[1] Quantitative evaluations of the environmental cost embodied in trade have been conducted by numerous studies at the global level (Davis and Caldeira, 2010; Peters and Hertwich, 2008; Skelton et al., 2011); and at the regional level, including for the US (Weber and Matthews, 2007), for Austria (Munoz and Steininger, 2010), for the Netherlands (Edens et al., 2011), for India (Goldar et al., 2011), for China (Liu and Ma, 2011) and for Estonia (Gavrilova and Vilu, 2012).

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and emissions intensity of its exports and has implemented policies to reduce export-embodied emissions.

In this paper, we analyze in detail China's trade-embodied CO_2 emissions and compare them to other major emitting regions. We then assess the impact policy could have on the magnitude of these emissions flows. Section 2 places our analysis in the context of relevant literature. Section 3 summarizes China's energy and climate policies that motivate this study. Section 4 describes our data and methods in detail. Section 5 presents the results of China's trade-embodied emissions in 2007 and an assessment of how proposed policies may change these emissions. Section 6 summarizes the results and offers some conclusions.

2. Literature review and motivation for this study

The magnitude of CO_2 emissions associated with China's trade has been widely studied. Previous research on China largely reflects three distinct lines of inquiry. First, researchers have used time series input–output databases for a single region to quantify trends in the emissions associated with China's trade. Weber et al. (2008) use this approach to show that China's emissions related to exports grow rapidly from 1987 to 2005, mainly due to rising consumption in developed countries. Yan and Yang (2010), Xu et al. (2011) and Minx et al. (2011) also use a single regional input–output (SRIO) approach to evaluate China's embodied emissions from 1992 to 1997, and adopt a structural decomposition analysis to investigate its drivers. A second focus of past work has been to analyze emissions transfers between China and one or more of its trade partners, including Japan (Dong et al, 2010; Liu et al., 2010), the U.S. (Du et al., 2011; Shui and Harriss, 2006), the U.K. (Li and Hewitt, 2008), and other Asian economies (Su and Ang, 2011). A third category uses sub-national input–output information—either alone or embedded in connection with international data—to study the magnitude of trade-related emissions across regions within China. For example, Guo et al. (2012) and Feng et al. (2013) have integrated China's provincial input–output data with international data to resolve domestic and international emissions transfers at the level of China's individual provinces. Su and Ang (2010, 2014) analyzed the effect of China's inter-regional trade and international trade on the domestic emissions through a hybrid emissions embodied in trade (HEET) approach.

From a methodological perspective, the embodied emissions literature can be separated into two categories. This acronym is defined above.SRIO analyses use an input-table for one region and approximate emissions embodied in trade flows by assuming that imports are produced using the same technologies as used for domestic production (see, for example, Dong et al., 2010; Du et al., 2011; Li and Hewitt, 2008; Liu et al., 2010; Minx et al., 2011; Shui and Harriss, 2006; Su and Ang, 2013; Su et al., 2013; Su et al. 2010; Weber et al., 2008; Xu et al., 2011; Yan and Yang, 2010). As illustrated by Su and Ang (2011, 2013) and Su et al. (2013), SRIO estimates can be biased as they neither distinguish technology differences between imported and domestic production nor capture feedback effects which occur when intermediate inputs with different carbon intensities are traded.

The second methodological category, multi-regional input–output (MRIO) analyses, addresses this shortcoming by using a global economic dataset in which countries are distinguished, bilateral trade flows are recognized, and imported and domestically produced intermediate inputs are tracked separately (Wiedmann, 2009; Wiedmann et al., 2007). MRIO approaches are adopted in global-scale analyses, such as Lenzen et al. (2004), Peters and Hertwich (2008), Davis and Caldeira (2010) and Peters et al. (2011b). Disadvantages of the MRIO approach include its extensive data requirements. In some sub-national analysis, the HEET approach, which combines the MRIO approach at the regional level and a SRIO approach at the national level, is applied to handle spatial aggregation bias at the regional level (Su and Ang, 2010, 2014). Beyond the input–output approaches, studies have also adopted computable general equilibrium (CGE) models to analyze the impact of policies on emissions embodied in trade. Examples include Babiker and Rutherford (2005), Boehringer et al. (2010), and Hübler (2011, 2012).

The contribution of the present study is twofold. First, we employ the approach used in Peters et al. (2011a) to generate a MRIO table based on the latest release of the GTAP database (Version 8, released in 2012 for the year 2007). The analysis allows us to compare on a consistent basis the direct and indirect emissions embodied in China's trade by sector with other regions and the global average. Second, with a better understanding of the origins of cross-regional differences in embodied emissions in hand, we develop and employ a multi-region, multi-sector static economy-wide model using this same data base. We use this model to assess the impact of two representative CO_2 control instruments in China aimed at reducing CO_2 emissions through changes in the sectoral structure (“economic rebalancing”) of the Chinese economy or its exports. Our representative policies are based on objectives set out in China's Twelfth Five-Year Plan (FYP) (2011–2015). Specifically, we simulate policies that 1) increase the service sector share of China's economic output, with and without a decrease in China's trade surplus, and 2) increase export taxes on energy-intensive sectors in China (equivalent to a reduction in export tax rebates).

3. Policy background

China's policymakers have set forth targets for reducing energy, CO_2-emissions, and other pollutants over the near term (in Five Year Plans) and the medium-to-long term. China implemented a number of administrative and financial policies to conserve energy and reduce emissions in its Eleventh FYP (2006–2010). Energy, CO_2 and pollution targets are contained in China's Twelfth FYP, and China's Copenhagen commitment to reduce CO_2 emissions intensity by 40–45% has been incorporated into China's Medium Term Energy Plan (2005–2020) (Industrial Energy Efficiency Database, 2012; Natural Resource Defense Council, 2012). Decision makers claim that policy approaches are intended to incentivize both technical progress and what is commonly termed “structural change” or “economic rebalancing” in directions that favor energy efficiency and energy savings.[2] One source estimates that over 70% of China's energy savings reflected the technical approaches—including investment in energy efficiency measures and the closure of the most inefficient enterprises—in the Eleventh FYP (Xie, 2012). The government has called for a series of subsidies and government investment initiatives to boost the services industry, targeting a GDP value share for services of 47% in 2015 (State Council of China, 2011). The reduction in industrial production is expected to have a large impact on China's trade pattern and scale, and also have an effect on CO_2 emissions embodied in traded goods and services.

In part to address the issue of trade-embodied carbon, China has implemented measures to control the export of “energy-intensive, pollution-intensive and resources-consuming” goods. Reductions in tax rebates and increases in export tariffs applied to energy-intensive products have been implemented gradually since 2004. In 2004, for the first time, China canceled the export tax rebate on coke to limit exports of this commodity. In 2005 and 2006, China reduced the tax rebate on exports of energy-intensive sectors such as coal, iron, and chemical goods, and in 2007 China cut tax rebates on around one third of its total traded goods, including many types of energy-intensive products. Due to the impact of the global economic crisis, China reinstated the tax rebate on some energy-intensive sectors in 2009, but canceled them again in 2010 (Reuters, 2012). Aside from the tax rebate, China has also used export taxes to limit the exports from energy-intensive

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[2] The term “economic rebalancing” is used in China to refer to two policy adjustments. The first is increasing the contribution of domestic consumption at the expense of overseas exports. In this connection, the Chinese government has announced a focus on increasing domestic demand as its primary task in the 12th FYP (China Daily 2012). Second, it is used to refer to shifting the industrial structure within China from predominantly heavy-industries to knowledge-intensive, high value-added industries such as services, which mostly have a lower energy footprint.

industries, which are included as a complementary measure in the Comprehensive Energy-saving Reduction Program Work Notice in China's Twelfth FYP (The State Council of China, 2011). In 2008, China increased the export tariff from 5% to 10% on steel and from 10% to 15% on nonferrous metals.

4. Methods and data

4.1. MRIO calculations of embodied carbon

As discussed in Section 2, MRIO approaches of embodied emissions are preferred to SRIO analyses because they explicitly represent heterogeneity in technologies used to produce imported and domestic intermediates and ultimately capture feedback effects discussed by Su and Ang (2011) and avoid issues associated with emissions assumptions for import and export identified by Su et al. (2013).

The development of MRIO models are well described in Lenzen et al. (2004), Peters and Hertwich (2008), Su and Ang (2011) and Boehringer et al. (2012). We adopt a similar MRIO structure to calculate the lifecycle carbon content embodied in production and ultimately trade flows. Input–output embodied-emissions analyses capture both direct CO_2 emissions from the combustion of fossil fuel and indirect CO_2 emissions associated with demand for intermediate non-fossil inputs and in their simplest form can be summarized using Eq. (1):

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

where $\boldsymbol{X}$ is a vector of total emission embodied in the production of each commodity (i), $\boldsymbol{I}$ is an identity matrix, $\boldsymbol{A}$ is an $i \times j$ matrix representing the use of industry j in industry i, and $\boldsymbol{E}$ is a vector of direct CO_2 emissions associated with each industry.

Following Boehringer et al. (2011), we extend this approach to a multi-region framework that is parameterized using the GTAP database. Specifically, we calculate the life-cycle carbon content associated with production of good i in region r as the carbon content per dollar of production, $Ay_{i,r,}$ multiplied by the value of production, $y_{i,r}$. This product is equal to the sum of direct emissions, $Ed_{i,r}$, and indirect emissions associated with intermediate non-fossil inputs from domestic sources, $Eid_{i,r}$, and imported sources, $Eim_{i,r}$, as described by Eq. (2).

$$Ay_{i,r} \times y_{i,r} = Ed_{i,r} + Eid_{i,r} + Eim_{i,r} \tag{2}$$

Direct emissions associated with energy consumption in sectoral production are included in the GTAP 8 database. To calculate indirect emissions, we exploit the input–output coefficients in the database. Indirect emissions from domestic intermediate inputs are calculated as:

$$Eid_{i,r} = \sum_j Ay_{j,r} \times y_{j,i,r} \tag{3}$$

where j indexes goods used as intermediate inputs in the production of good i.

Indirect emissions from imported intermediate inputs are the sum of emissions associated with the production of those intermediates and emissions from international transportation:

$$Eim_{i,r} = \sum_{j,s} \left(Ay_{j,s} \times y_{j,i,s,r} + At_{j,r} \times y_{j,i,s,r} \right) \tag{4}$$

where $y_{j,i,s,r}$ is the quantity of imported input j used in the production of good i imported from region s in region r, and $At_{j,r}$ is the per-dollar carbon content of transportation services required to deliver good j to region r, which is calculated using Eqs. (5) and (6):

$$At_{j,r} = \left(\sum_{t,s} vtwr_{t,j,s,r} \times ATr_t \right) \Big/ \sum_{t,s} vtwr_{t,j,s,r} \tag{5}$$

$$Atr_t = \left(\sum_r vst_{t,r} \times Ay_{t,r} \right) \Big/ \sum_r vst_{t,r} \tag{6}$$

In Eq. (5), $vtwr_{t,j,s,r}$ is the value of good j transported from region s to region r by service t (t includes air transport, water transport and land transport), and ATr_t is the average carbon content of transport service t. In Eq. (6), $vst_{t,r}$ and $Ay_{t,r}$ are, respectively, the quantity of transportation service t and the per dollar carbon content of transport service t supplied by region r.

Substituting Eqs. (3)–(6) into (2) yields a system of $i \times r$ simultaneous equations, where the lifecycle per-dollar carbon content of each good ($Ay_{i,r}$) is an endogenous variable and other variables ($Ed_{i,r}$, $Eid_{i,r}$, $Eim_{i,r}$, $At_{j,r}$, ATr_t, $vtwr_{t,j,s,r}$, $vst_{t,r}$, $y_{i,r,}$ $y_{j,i,r}$, $y_{j,i,s,r}$) are exogenous and are sourced from the GTAP database. Emissions embodied in bilateral trade are calculated by multiplying $Ay_{i,r}$ by trade flow values.

Several studies have shown that sectoral and regional aggregation choices are important when applying a MRIO analysis. The general conclusion from this literature is that a detailed aggregation is preferred to a coarse aggregation (see, for example, Lenzen, 2011; Su and Ang, 2010, 2012; Bouwmeester and Oosterhaven, 2013), although there can be a limit to benefits from disaggregation beyond a certain level (Andrew et al, 2009; Su et al., 2010). To provide a detailed representation of key energy traded sectors, we maintain the GTAP disaggregation for all industries except those in the agriculture and services sectors, which account for a small proportion of China's trade. Specifically, our aggregation identifies three primary energy sectors (Coal, Crude oil, and Natural gas), Electricity, and six energy-intensive sectors (Paper and paper products; Chemical, rubber and plastic products; Non-metallic minerals; Iron and steel; Fabricated metal products; and Non-ferrous metals). Following the same logic as our sectoral choices, our regional aggregation identifies political entities that account for large shares of China's total trade, including the US, Japan, Korea and the EU, while composite regions are included for other regions. Our aggregation routine follows techniques developed by Rutherford (2005). Detailed sectoral and regional aggregations are listed in Table 1.

Table 1
Sectoral and regional aggregation.

Sector	Abbreviation	Region	Abbreviation
Agriculture	agr	China	chn
Coal	col	Japan	jpn
Oil	oil	Korea	kor
Natural gas	gas	Taiwan	twn
Refined oil	roil	India	ina
Electricity	ely	United States	usa
Paper & paper products	ppp	Russia	rus
Chemical, rubber & plastic products	crp	Australia–New Zealand	anz
Non-metallic minerals	nmm	Europe	eur
Iron & steel	i_s	Rest of Europe	roe
Fabricated metal products	fmp	Africa	afr
Non-ferrous metals	nfm	Middle East	mes
Food production	fod	Latin America	lam
Metal ores	omn	Rest of East Asia	roa
Textiles	tex	South Asia	sea
Wearing apparel	wap	Canada–Mexico	rna
Leather product	lea		
Wood products	lum		
Electronic equipment	ele		
Machinery and equipment nec*	ome		
Manufactures nec*	omf		
Transport equipment	tre		
Transport service	trs		
Services	ser		

Note: * The abbreviation nec stands for not elsewhere classified.

4.2. Building a CGE model for policy assessment

To assess the impact of current policies on the reduction of trade-embodied carbon emissions in China, we employ a multi-sector, multi-region static CGE model of the global economy. The CGE model is built on the same data as that used to calculate trade-embodied CO_2 emissions but extends our MRIO analysis by allowing producers and consumers to respond to changes in relative prices. That is, following changes in a policy instrument (e.g., an export tax), producers can alter input choices and consumers can change their consumption bundles. In our CGE analysis, embodied CO_2 emissions are endogenous and are re-calculated for each simulation.

The structure of the CGE model is similar to the GTAP-EG model described by Rutherford and Paltsev (2000) and the static component of the MIT Emissions Prediction and Policy Analysis (EPPA) model (Paltsev et al., 2005). In the model, there are three types of production processes: extraction of primary fuels (crude oil, coal and gas), production of electricity, and other production activities including refined oil, manufacturing and services. Each of the production technologies is captured by a nested constant elasticity of substitution (CES) function. Detailed nesting structures for the three production activities are portrayed in Fig. 1, where σ is used to denote elasticities of substitution. An important feature of the nesting structure is the ability for firms to substitute among fossil fuels and between aggregate energy and value added. Scarcity of fossil fuels is captured by including a fuel-specific resource in the top level of each fossil fuel production nest. Elasticity values for the CGE model follow those used in the MIT EPPA model. Firms are assumed to operate in perfectly competitive markets. The production functions also include taxes on output, inputs and traded commodities observed in the benchmark database.

On the demand side, a representative household in each region maximizes utility by allocating income across current consumption, investment and government expenditure. Current consumption in each region is determined by a series of nested CES functions of the commodities listed in Table 1. To allow alternative substitution possibilities between energy and non-energy commodities, the nesting structure splits consumption into an energy composite and other goods and services. Investment, which is used to fund additions to the capital stock in subsequent periods, and government expenditure, which provides goods and services for the representative household, are both assumed to be constant proportions of total income. Consumers chose their demand profile to maximize their welfare subject to budget constraints and receive income from payments to capital, labor, and energy resources (factor income) and tax revenue.

Bilateral trade is specified using the Armington assumption that domestic and imported goods are imperfect substitutes and are distinguished by region of origin (Armington, 1969). That is, each commodity entering final demand and purchased by firms is a CES composite of a domestic variety and an imported variety, where the imported variety is a further CES composite of varieties from different regions.

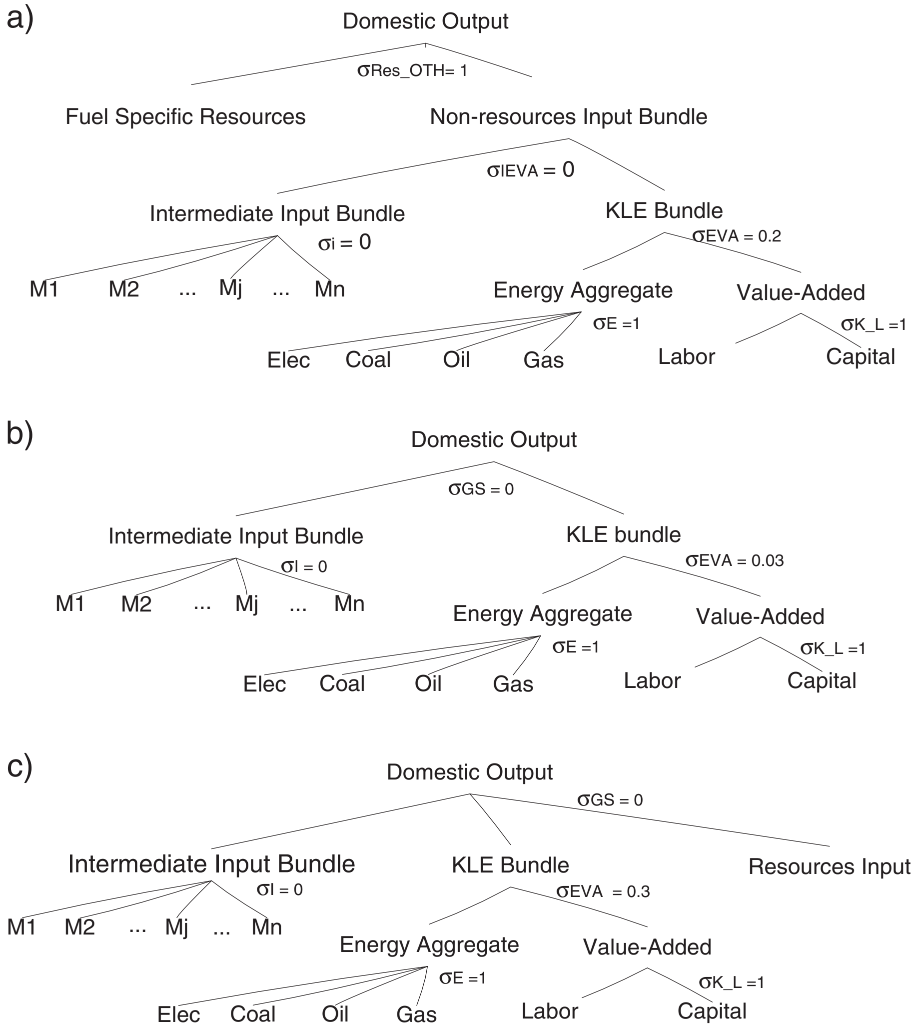

Fig. 1. The nesting structure of production sectors for (a) primary fuels (coal, crude oil and gas), (b) electricity, and (c) other sectors. *Note*: Elasticity values are sourced from the MIT EPPA model (Paltsev et al., 2005).

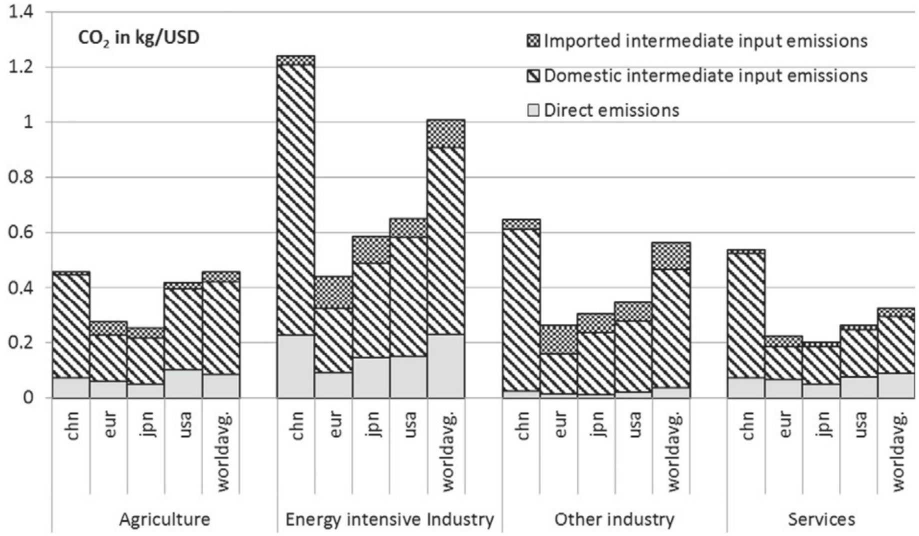

Fig. 2. CO_2 intensity by sector and source, 2007.

The CGE model is calibrated using the MRIO database (GTAP 8) that is used to analyze embodied carbon emissions. The model is formulated as a mixed complementarity problem using the mathematical programming system (MPSGE) language, which is a subsystem of the General Algebraic Modeling System (GAMS), and solved with the PATH solver to derive the vector of prices that clears the market and the associated demands across all sectors (Mathiesen, 1985; Rutherford, 1995; Rutherford, 1999).

4.3. Policy scenarios

We evaluate the impact of two policy scenarios on China's net exports of CO_2 emissions. Under the Twelfth FYP, China's policymakers aim to encourage adjustment in the country's economic structure to reduce reliance on heavy industry and increase the contribution of services to GDP, while simultaneously encouraging domestic consumption. We include two scenarios that capture the critical features of these policies. Our first scenario, Rebalance, imposes sectoral GDP contributions for 2015 set out in China's Twelfth FYP. The second scenario, Demand, simulates an increase in domestic demand in addition to changes in sectoral GDP contributions. According to a report by the Development Research Center of the State Council (Xinhua, 2010), China's 2015 target for the contribution of agriculture to GDP is 8%, for industry is 45% and for services is 47%. In the GTAP 8 database, the contribution of agricultural, industry, and services to GDP is 12%, 48% and 40%, respectively. In the Rebalance and Demand scenarios, we simulate the 2015 targets using endogenous output taxes or subsidies, where the same endogenous instrument is applied to sectors within each broad sectoral group. In the Demand scenario, in addition to the sectoral targets, we decrease the value of China's trade surplus by 50%, from $270 billion in the GTAP 8 database to $135 billion. The shock is implemented by exogenously decreasing China's capital account deficit and increasing capital accounts for other regions by equal proportions so that global trade is balanced.[3]

As noted earlier, in recent years, China has acted to control the export of energy-intensive products by reducing the tax rebate on exports and increasing export tariffs on production activities in these sectors, and such policies are also included in the Twelfth FYP (The State Council of China, 2011). As reducing tax rebates on exports and imposing an export tax operate through essentially the same mechanisms, we increase export taxes in our third scenario, which we label Exp-Tax. The Exp-Tax scenario does not include either of the policy shocks implemented in previous scenarios.

In our model, energy-intensive sectors include Paper and paper products, Chemical, Rubber and plastic products, Nonmetallic mineral products, Iron and steel, Non-ferrous metals, and Fabricated metal products. Current export tariffs on these products range from 4% to 6%. As export tariffs on these sectors are not set out explicitly in China's Twelfth FYP or elsewhere, we make the simple assumption in our scenario that current tax rates are doubled in our Exp-Tax scenario.[4]

5. Results

In this section, we describe China's trade-embodied carbon emissions in 2007 based on the results of our MRIO analysis. We then use the CGE model to simulate the three policy shocks as described above and evaluate the impact on the economy, total emissions, and China's trade-embodied CO_2 emissions.

5.1. CO_2 emissions embodied in China's trade

To derive trade-embodied carbon emissions observed in our benchmark dataset, we multiply sector- and origin-specific carbon intensities ($Ay_{i,r}$) by China's export and import values. Fig. 2 presents CO_2 intensities by source for aggregated sectors and regions. The results reveal that sectoral carbon intensities in China are much higher than those in Europe, Japan and the U.S., and are also higher than the global average.[5] The results further show that domestic intermediate input emissions, which are mainly due to direct and indirect use of electricity, are the largest contributor to life-cycle embodied emissions, rather than direct emissions.

CO_2 emissions embodied in China's imports and exports by region are displayed in Fig. 3. The calculations show that China is a net exporter of embodied emissions to all regions in our analysis except for Taiwan. Su and Ang (2011) derive similar results using a dataset for a different year with an alternative coverage or world regions. This outcome is driven by China running a trade surplus with most regions and having

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[3] An alternative method to decrease the trade surplus is to endogenize the balance of trade and introduce a policy instrument, as in Li and Whalley (Li and Whalley, 2012).

[4] Defining a precise tax rate is not necessary here as we are focusing on providing a performance benchmark for a potential policy instrument rather than aiming to inform the choice of tax rates.

[5] We convert among currencies using market exchange rates. If purchasing power parity exchange rates are used, carbon intensities in China are closer to the world average level but remain above those in the US, Europe, and Japan.

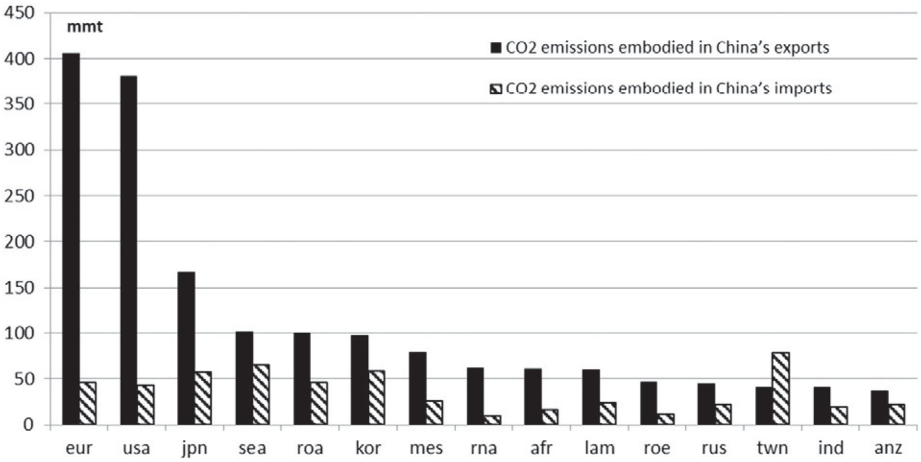

Fig. 3. CO_2 emissions embodied in China's exports and imports by region, 2007.

carbon intensive production relative to elsewhere. Europe, the United States and Japan are China's largest trade partners, and combined account for more than half of China's total net exports of embodied CO_2. In aggregate China exports 1722 mmt (million metric tons, mmt) of embodied CO_2 and imports 545 mmt, resulting in net exports of 1177 mmt. In comparison, CO_2 emissions in China in 2007 were 5269 mmt, so the production for export accounted for 32.7% of total emissions and net exports of CO_2 were equivalent to 22.3% of total emissions. These results are consistent with findings from previous studies. Export-embodied emissions were estimated to be 24% of total emissions in 2002 (Pan et al., 2008), 33% in 2005 (Weber et al., 2008) and between 27% and 33% in 2007 (Minx et al., 2011; Yan and Yang, 2010).[6] Lin and Sun (2010) find that the net export embodied CO_2 emissions account for 18.8% of total emissions in 2005. The allocation of embodied emissions among traded sectors is shown in Fig. 4.

To determine the drivers of sectoral embodied CO_2 emissions, we plot China's sectoral export value shares against sectoral life-cycle carbon intensities in Fig. 5. We find that some of the least emissions-intensive sectors have a high value share, while some of the most emissions-intensive sectors are small contributors to China's total exports. As shown in Fig. 5, Electricity (ely) and Gas (gas) production are the two most carbon intensive sectors in China but there is little export of these goods. Energy-intensive sectors, such as Non-metallic minerals (nmm), Fabricated metal products (fmp), and Iron and steel (i_s), have relatively high carbon intensities but their trade volumes are generally small, together accounting for only 20% of total exports. Electronic equipment (ele) and Machinery and equipment (ome) account for 22% and 18%, respectively, of total trade in value terms. Although the CO_2 intensities of these sectors are relatively low, significant export shares result in these commodities accounting for large proportions of China's net exports of embodied CO_2.

5.2. CGE simulation results

As noted in Section 3, we evaluate the impact of three scenarios on China's net exports of embodied CO_2 emissions. First, our Rebalance scenario uses endogenous output subsidies and taxes to increase the output of services and decrease the output of both agriculture and industry. Second, the Demand scenario, in addition to targeting the same output changes as in the Rebalance scenario, reduces China's trade surplus by 50% in order to simulate an increase in domestic demand. Finally, our Exp-Tax scenario increases taxes on China's energy-intensive exports (without any other policy shocks).

Fig. 6 displays the value of China's net exports for aggregated sectors.[7] In the Rebalance and Demand scenarios, taxes/subsidies to achieve sectoral targets increase the price of industry output by 20% and decrease that for services by 25%, compared to the reference case. As a result, in both scenarios, there are decreases in net exports of both energy-intensive products and other industry, and a large increase in exports of services, which transforms China from a net importer to a net exporter of services. Comparing results for the two scenarios indicates that, as expected, increasing domestic demand reduces the net exports of all sectors.

As relative price changes due to the policy shocks induce changes in input choices, we re-estimate our MRIO calculations of embodied emissions using production coefficients predicted by our CGE model under each policy scenario. China's net exports of embodied CO_2 for aggregate sectors and emissions by region are reported in Table 2. In the Rebalance scenario, driven by the large policy-induced increase in services output, net exports of emissions embodied in industry decrease and emissions embodied in services increase. On balance, there is only a small (4.2%) decrease in emissions embodied in China's net exports in the Rebalance scenario. The sectoral pattern of changes in embodied emissions in the Demand scenario is similar to that in the Rebalance scenario, but the decrease in net exports results in a much larger decrease in total net exports of emissions (22.1%).

By examining CO_2 emissions by region (reported in the second panel of Table 2), we find that policies in China affect emissions in other regions through bilateral trade linkages. In the Rebalance and Demand scenarios, promoting services at the expense of manufacturing decreases China's domestic emissions by about 5%. However, the reduction of manufacturing exports from China induces other regions to expand production, so emissions in other regions increase. The largest increases in emissions are observed for Europe, Japan and Korea, which combined account for about 30% of the increase in emissions elsewhere. There is also a large increase in trade between emerging Asian economies and developed countries, which increases emissions in the exporting regions. Specifically, exports from the Rest of Asia (ROA, which includes Vietnam, Cambodia, and Laos) to Europe, Japan and the US increase by around 8%. In aggregate, reductions in CO_2 emissions in China translate into increased emissions elsewhere (i.e., there is leakage of emissions) in part because developed economies increase production of industrial commodities previously purchased from China and in part because other emerging economies produce more industrial goods for export to developed markets. The net effect is

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[6] Related to our analysis but not directly comparable, Chen and Zhang (2010) find that export-embodied emissions account for 41% of China's greenhouse gas emissions.

[7] As we wish to focus on changes for energy-intensive industries, we report results separately for energy-intensive industries and other industries, even though the same tax rates are applied to all industrial sectors in the Rebalance and Demand scenarios.

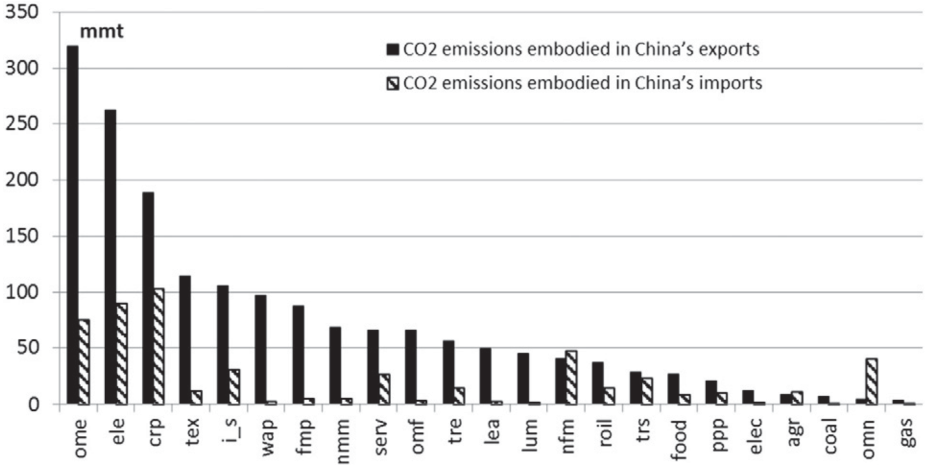

Fig. 4. CO_2 emissions embodied in China's exports and imports by sector, 2007.

only a small reduction in global CO_2 emissions (225 mmt in both the Rebalance and Demand scenarios) due to the benefits of cleaner technology in advanced countries and a lower overall emissions intensity in developing countries that replace production in China (e.g., ROA has an emissions intensity of 1.27 kg of CO_2 per dollar compared to China's 1.77, with the discrepancy largely due to the lower reliance on coal in electricity production in ROA).

In the Exp-Tax scenario, increasing export taxes on energy-intensive products decreases exports of these commodities from $211 billion to $173 billion. The reduction in energy-intensive production reduces energy and factor prices. These price decreases reduce the production cost for other sectors, which result in these sectors becoming relatively more competitive in global markets and leads to an increase in exports of non-targeted sectors (except for agriculture).

Trade and production in the Exp-Tax scenario result in emissions embodied in energy-intensive industry decreasing by 86 mmt. However, net exports of emissions in other sectors increase by 42 mmt, so the decrease in total net exports of embodied emissions is only 44 mmt, a 3.7% decrease. The decrease in emissions in China is also partially offset by the leakage of emissions to other regions (of 29 mmt). This is because reductions in exports of energy-intensive products from China induce increased production of these goods in other regions, while there is a small net decrease in total consumption of energy-intensive products. The largest increases in emissions are observed for Europe, the U.S. and Japan, and imports of energy-intensive commodities to China from developing countries increase. As in the Rebalance scenario, a reduction in the supply of Chinese-made energy-intensive goods to developed countries is partially compensated by production in advanced economies and in other regions that export to the advanced economies. In addition to changes in trade patterns, a small proportion of leakage of emissions outside of China is due to a fossil-fuel price effect. Under this mechanism, a reduced demand for fossil fuels in China decreases global prices for fossil fuels and increases their use in other regions. Combined with the increase in emissions from non-targeted sectors in China, the increase in emissions elsewhere in the Exp-Tax scenario leads to only a small reduction in global emissions.

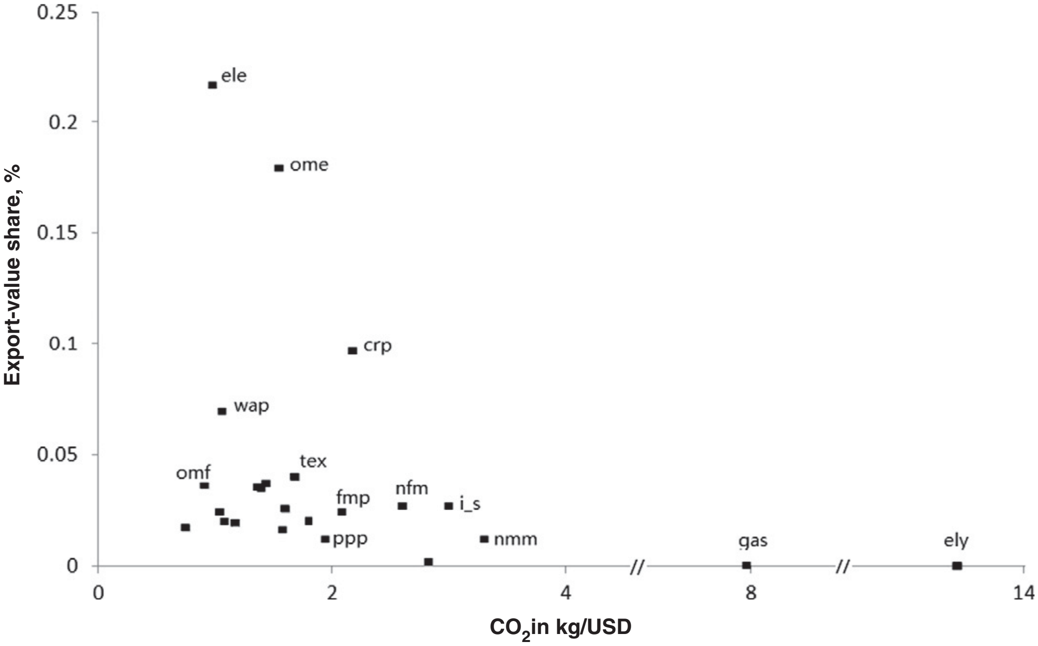

Fig. 5. China's sectoral export value shares and CO_2 intensities, 2007.

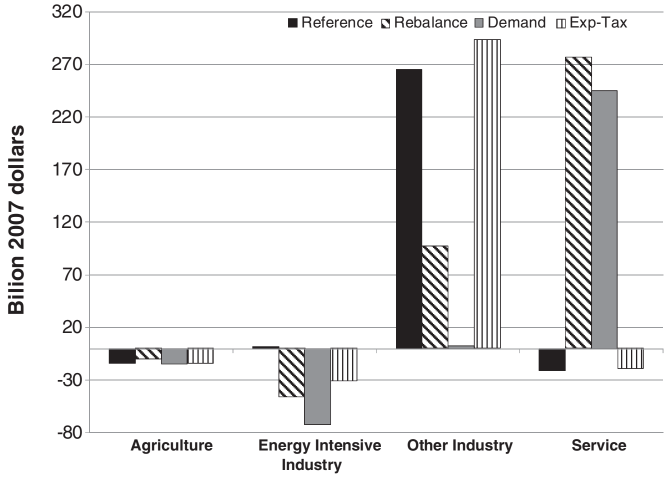

Fig. 6. China's net exports in the reference and policy scenarios.

6. Conclusions and discussion

We analyzed carbon emissions embodied in China's trade in 2007 by conducting a MRIO analysis using the GTAP 8 database. Insights from the MRIO analysis helped to guide our investigation of the impact of two representative policies aimed at reducing CO_2 emissions through changes in China's economic structure using a multi-region, multi-sector static global general equilibrium model. As the world's largest exporting country, China's net exports of embodied carbon are greater than those of other regions. Large exports of embodied CO_2 emissions in China threaten the domestic environment and also make China a major target for carbon tariff policies implemented overseas. China has become aware of its vulnerabilities, and has taken measures to address concerns surrounding energy and carbon emissions embodied in its trade through a range of policy approaches. This paper has provided insight into the factors influencing China's trade-embodied emissions. It has also attempted to evaluate the effect of two policies representative of measures included in China's Twelfth FYP—one focused on economic rebalancing, with and without an emphasis on stimulating domestic consumption, and the other focused on reducing incentives for China to export energy-intensive products.

In the MRIO analysis, we find that the CO_2 emissions embodied in China's net exports are 1176 mmt, equivalent to 22% of its total emissions. This total is consistent with the findings of other studies, including estimates of emissions embodied in China's exports and imports in Yan and Yang (2010) and Weber et al. (2008). Mechanical and electronic equipment products are the major sources of CO_2-embodied net exports (34%) rather than the energy intensive sectors (30%). Trade with Europe, Japan, and the U.S. account for more than half of China's total net exports of embodied carbon. The carbon intensities of production in China were found to be much higher than those in Europe, Japan and the U.S. In China, relatively CO_2-intensive production, particularly for electricity, and a trade surplus were found to be the main drivers of substantial net exports of embodied CO_2 from this country.

Although both measures have been advertised as CO_2 reduction policies, neither of the two policies we investigate has a significant impact on total global CO_2 emissions. The policy aimed at rebalancing China's economic structure altered China's trade patterns, from industry-based to service-based, but did not significantly influence China's trade-embodied CO_2 emissions, unless there was a decrease in China's trade surplus (in which case domestic emissions increased and offset 90% of the reduction in trade-embodied emissions). Tariffs on energy intensive products reduced China's energy-intensive exports by $30 billon, but only reduced China's total export-embodied CO_2 emissions by a small amount, due to the offsetting effect caused by an increase in other production activities. A policy that targets the expansion of domestic demand is observed to be more effective at reducing China's export-embodied CO_2 emissions, although it does not explicitly take into account shifts in consumption patterns that may occur as household incomes increase. In both scenarios, we find that around 90% of the decreases in emissions in China would be offset by relocation of production to the advanced economies, where the products are consumed, and by increased production in other trade partners. As a result, climate policies implemented in China would indirectly lead to emissions leakage to other regions and have little environmental benefit. Globally, there was a small decrease in CO_2 emissions, as regions with less CO_2-intensive technologies produce energy-intensive output previously made in China.

The estimates of embodied carbon emissions are sensitive to trade values and patterns. Given the limited availability and long lead times that precede the release of global input–output dataset, we conduct our research based on 2007 data. However, with the impact of global economic slowdown starting in 2008, China's trade surplus has shrunk from 261.8 billion dollars in 2007 to 155.1 billion dollars in 2011 (National Bureau of Statistics of China, 2011; National Bureau of Statistics of China, 2012). Meanwhile, if the current expansion of China's domestic demand continues, it is predicted that China may rank as the top global importer within a few years (Xinhua, 2012). If this occurs, China's trade surplus would be further reduced relative to that in our database. Concerns around trade-embodied carbon emissions would be potentially mitigated or replaced by concerns about the energy and CO_2 intensity of China's domestic consumption. Furthermore, the impact of the policies discussed in this paper on CO_2 emissions is limited, in part because these policies do not address the potential for displacing emissions from targeted industries to other sectors.

Table 2
CO_2 emissions embodied in China's net exports and by emissions by region (mmt).

	Reference	Rebalance	Demand	Exp-Tax
China's net exports of emissions				
Agriculture	−2	0	−3	−2
Energy-intensive industry	312	214	158	226
Other industry	827	588	472	867
Services	40	325	290	42
Total	1177	1127	917	1133
Emissions by region				
China	5268	4986	5011	5239
U.S.	5583	5585	5582	5584
Europe	4150	4157	4155	4152
Japan	1067	1073	1072	1068
Korea	424	430	429	425
Taiwan	258	262	261	259
Rest of East Asia	474	482	482	475
Rest of world	9299	9327	9304	9306
Global	26,523	26,302	26,296	26,508

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