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Input-output and structural decomposition analysis of Singapore's carbon emissions

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ABSTRACT

Singapore is an island city-state. It lacks conventional energy resources and is alternative energy disadvantaged. In the past decade (2000–2010), its energy-related carbon emissions increased from 37.8 to 44.4 million tonnes of CO_2. This paper analyses the city state's carbon emissions from the demand perspective using the input-output (I-O) method and investigate the drivers of emission changes using structural decomposition analysis (SDA). It is the first comprehensive analysis of Singapore's emissions using the I-O framework. The results obtained show that exports accounted for nearly two-thirds of its total emissions and growth in its emissions in the last decade was largely export-driven. Emissions increased as export-oriented industries and export volume expanded. Fuel switching and energy efficiency, however, helped to lower growth in emissions. Besides exports, household-related emissions accounted for about a quarter of Singapore's total emissions. The emissions related to different household groups remained fairly stable as increases in embodied (indirect) emissions were offset by decreases in direct emissions. The high-income household group registered the largest increase in direct emissions, while the middle-income household group registered the largest increase in embodied emissions. The policy implications of our findings are discussed.

1. Introduction

Combating against climate change requires worldwide effort. The COP 21 held in Paris in late 2015 calls for limiting global temperature rise to below 2 °C. However, based on the climate action plans submitted by world countries prior to COP 21, the pledges will not be sufficient to meet the below 2 °C target (UNFCCC, 2016a). The climate negotiations in Paris also highlighted the fact that countries have common but differentiated responsibilities. Considering the national circumstances, the Paris Agreement requires countries to put forward their best efforts under the “nationally determined contributions” (NDCs) and to strengthen these efforts in the years ahead (UNFCCC, 2016b). Regular reporting of the emissions and progress made are required. As a result, there is an increasing need for countries to better understand the impacts of their past efforts, examine their current climate policy and mitigation measures, and further explore mitigation opportunities such as through technology innovation, investment, market mechanisms and regional collaborations.

Singapore is an island city-state which lacks conventional energy resources. It has a land area of only 719 square kilometers and a population of 5.54 million in 2015. It currently contributes around 0.11% of global GHG emissions. Although there is no obligation under the Kyoto Protocol, Singapore has in 2010 embarked on policies and measures to reduce its emissions by 7–11% below 2020 business-as-usual level (NCCS, 2012). From 2015, it further aims to reduce emission intensity, given by the ratio of total greenhouse gas emissions to GDP, by 36% from 2005 level by 2030 and stabilize its emissions with the aim of peaking around 2030 (NCCS, 2015). An inter-ministerial committee on climate has been tasked to drive the whole-of-government effort to develop Singapore's climate change mitigation measures.

Singapore has limited access to alternative energy sources. Its energy consumption has been heavily dependent on imported oil and, in more recent years, imported natural gas as well. There are very few options it can take to mitigate emissions in the short and medium terms. The strategies it has so far identified and implemented are energy efficiency for all sectors of the economy and switching from oil to natural gas in electricity generation. In the last decade (2000–2010), Singapore's GDP increased by 76% but its carbon emissions increased by only 18%. This translates to a reduction in the emission intensity of 33% from 2000 to 2010. It is not certain to what extent this

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Table 1
Structure of the I-O tables with non-competitive imports assumption.

	Intermediate Transactions	Final Demands	Total Outputs
Intermediate Inputs	Z_d	$y_{df} + y_{ex}$	x
Imports	Z_i	y_i	$y_m = Z_i \cdot 1 + y_i$
Value Added	v'		
Total Inputs	x'		

reduction was the results of the mitigation measures taken linked to the above strategies or of changes in the structure of the economy or demand patterns.

In 2015, Singapore's international trade (both imports and exports combined) amounted to 884 billion Singapore dollars (SGD), or 2.2 times of its GDP of 402 billion SGD. With a strong export-oriented manufacturing base, Singapore's energy-related carbon emissions are fairly unique and are heavily depend on the international demands of the goods and services it produces. Given the constraints it is facing in switching to clean alternative energy sources, it is doubly important to conduct a rigorous assessment of the progress it has made in emission mitigation. This includes, for example, how growth in emissions was driven by the various final demand categories (including exports) and energy efficiency, as well as the effectiveness of the mitigation measures it has undertaken.

Input-output (I-O) analysis allows direct and embodied (or indirect) emissions by industry sector and final demand to be estimated at a disaggregated level. Since the introduction of the environmental-extended I-O framework, I-O techniques have been widely used in energy and emissions studies. See, for example, Kok et al. (2006), Wiedmann et al. (2007), Hoekstra (2010), Su and Ang (2012a), Sato (2014) and Hawkins et al. (2015). More recently, the I-O based structural decomposition analysis (SDA) has also been widely used by researchers to study the drivers of changes in total or embodied emissions over time.[1] The latest methodological developments in SDA can be found in Su and Ang, (2012a, 2012b, 2014, 2015, 2016), Su et al. (2013), and Su and Thomson (2016).

In the literature, emission studies using the I-O or SDA analysis cover a wide spectrum of geographical regions, countries and cities. So far, only three studies include Singapore. They are Peters and Hertwich (2008), Su et al. (2010) and Peters et al. (2011). These three studies deal mainly with trade-related embodied emissions.[2] None of them gives a full treatment of emissions related to all demand categories (i.e. private consumption, government consumption, gross fixed capital formation, changes in inventory and exports) and drivers of emission changes. This study is an attempt to fill the gaps. It is the first comprehensive analysis of Singapore's carbon emissions using the I-O framework.[3] In addition, in this study, the household sector is disaggregated into different household groups by household income. The findings will be useful for evaluating the impacts of recent energy efficiency and emission reduction initiatives as well as for developing future policy.

A unique feature of this study is that it provides insight into the impacts of mitigation measures taken by a city state which is alternative energy disadvantaged and has limited mitigation options. Another interesting feature is that it concurrently applies the I-O analysis and the SDA method which is not often found in the literature. Section 2 introduces the methodology of I-O analysis of carbon emissions and SDA of emission changes. The study of Singapore's carbon emissions is presented in Section 3. Policy implications of the finding are discussed in Section 4.

2. Method

2.1. Input-output analysis of carbon emissions

The economic I-O analysis framework is extended to the environmentally-extended I-O analysis in Isard et al. (1968) and Leontief (1970). In embodied emission studies using the extended I-O framework, an important issue is the imports assumption. Following the recommendations in Su and Ang (2013), the non-competitive imports assumption is adopted in this study. The structure of I-O tables with non-competitive imports assumption is shown in Table 1. For such I-O tables, the standard Leontief I-O model can be formulated as

$$x = Z_d \cdot 1 + (y_{df} + y_{ex}) = A_d x + (y_{df} + y_{ex}) \quad (1)$$

where x is the vector of total outputs, Z_d is the matrix of domestic intermediate demands, 1 is the vector with all the elements equal to one, $A_d = Z_d \cdot (\hat{x})^{-1}$ is the matrix of domestic production coefficients, y_{df} is the vector of domestic final consumption, and y_{ex} is the vector of domestic exports.

Rearranging Eq. (1) leads to the following basic equation for Leontief I-O analysis with non-competitive imports,

$$x = (I - A_d)^{-1}(y_{df} + y_{ex}) = L_d(y_{df} + y_{ex}) = L_d(y_{pc} + y_{gc} + y_{gfcf} + y_{ci} + y_{ex}) \quad (2)$$

where $L_d = (I - A_d)^{-1}$ represents the domestic Leontief inverse matrix, domestic final consumption (y_{df}) is the summation of private consumption (y_{pc}), government consumption (y_{gc}), gross fixed capital formation (y_{gfcf}), and change in inventory (y_{ci}).

With the emission intensity vector f representing the CO_2 emissions per unit of value of industry output, the total amount of CO_2 emissions from production can be formulated as

$$\begin{aligned} C_{tot} &= f'x = f'(I - A_d)^{-1}(y_{fd} + y_{ex}) = f'L_d(y_{pc} + y_{gc} + y_{gfcf} + y_{ci} + y_{ex}) \\ &= f'L_d y_{pc} + f'L_d y_{gc} + f'L_d y_{gfcf} + f'L_d y_{ci} + f'L_d y_{ex} \\ &= C_{pc} + C_{gc} + C_{gfcf} + C_{ci} + C_{ex} \end{aligned} \quad (3)$$

where $C_{pc} = f'L_d y_{pc}$ is the emissions embodied in private consumption, $C_{gc} = f'L_d y_{gc}$ is the emissions embodied in government consumption, $C_{gfcf} = f'L_d y_{gfcf}$ is the emissions embodied in gross fixed capital formation, $C_{ci} = f'L_d y_{ci}$ is the emissions embodied in change in inventory, and $C_{ex} = f'L_d y_{ex}$ is the emissions embodied in exports.

Carbon emissions associated with household consumption include both the direct and embodied emissions. In the literature, household-related embodied emissions are also called household's indirect emissions. While the latter is more commonly used for the household sector, for consistency we shall use "embodied emissions" so that the term used is consistent throughout the whole paper. The direct emissions are calculated using household's direct energy consumption, while embodied emissions are the same as the emissions embodied in private consumption C_{pc} in Eq. (3). With the household sector divided into different household groups, the total emissions from household consumption can be formulated as

[1] SDA and index decomposition analysis (IDA) are the two most commonly used decomposition techniques in energy and emission studies. A comparison between them can be found in Su and Ang (2012a). In the literature, these decomposition techniques are mainly used to study changes over time, i.e. temporal decomposition. Recently, this has been extended to spatial decomposition. See Ang et al., (2015, 2016) on IDA and Su and Ang (2016) on SDA.

[2] Su et al. (2010) analyze the impacts of sector aggregation on Singapore's emissions embodied in exports. Peters and Hertwich (2008) and Peters et al. (2011), which cover world countries with Singapore as one of the countries, deal with embodied emissions in trade and the resulting consumption-based emissions using emissions embodied in bilateral trade (EEBT) and multi-regional input-output (MRIO) approaches (Su and Ang, 2011).

[3] None of previous studies applies the I-O framework to analyze Singapore's carbon emission issues. A reason is the lack of disaggregated energy consumption data to support the energy and environmental I-O analysis.