Ecological Indicators 94 (2018) 74–82

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

How external trade reshapes air pollutants emission profile of an urban economy: A case study of Macao

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ARTICLE INFO

Keywords:
Air pollutants
Urban economy
Macao
Trade
Multi-regional input-output analysis

ABSTRACT

External trade has been approved to greatly affect environmental emissions by typical heterotrophic urban economies. However, the answers to questions such as how the trend of air pollutant embodied in external trade changes and what are the key influential factors need further exploration. Given that, using Macao as a case study, this paper first investigates the temporal evolution of 5 important air pollutants (i.e., SO_2, PM_{10}, NMVOC, NO_X, and CO) emissions embodied in external trade based on the multi-regional input-output analysis, and then dissects the effects of key trade factors on air pollutant emissions by using the dynamic regression model. The results show that large amounts of air pollutants emissions have been avoided in Macao via increasing net imports, indicating that the direct emission reduction is achieved by transferring the emission-intensive industries to other regions. Specifically, the air pollutants emissions embodied in imports increased from 1.61E+05 t in 2000 to 2.77E+05 t in 2013. Besides, the air pollutants emissions embodied in exports increase from 1.60E+05 t in 2000 to 2.53E+05 t in 2013, dominated by gaming industry. On the other hand, the dynamic regression results reveal that there is a positive correlation between the total embodied emissions and both the growth of GDP per capita and imports, while factors such as exports growth can help decrease Macao's air pollutants emissions. Hence, a set of relevant air-pollution abatement strategies from both the local and global perspectives are proposed in this study.

1. Introduction

A large number of cities worldwide are now suffering from serious air pollution. According to the most recent Urban Air Quality Database, the particulate matter (PM_{10} and $PM_{2.5}$) pollution levels in more than 2000 cities exceed the World Health Organization recommended standards (WHO, 2016), exerting adverse impact on human health and the environment in urban areas (Jiao et al., 2018; Ngo et al., 2018). This situation is even worse in developing countries such as China, India, etc. As reported by Asian Development Bank (ADB), less than 1% of China's 500 mega-cities met WHO's air quality standards in 2016 (ADB, 2012). The ever-increasing urban population, projected to double by 2050 (Defries et al., 2010), will inevitably induce even greater air pollutant emissions, exhibiting the major role urban cities must play in regards to mitigating global air pollutants emissions.

To address this immense global issue, many studies on urban air pollution have been carried out (Deng et al., 2016; Islam et al., 2016; Liu and Wang, 2017; Su et al., 2013; Xu and Dietzenbacher, 2014). As urban economies have become increasingly involved in domestic and foreign supply chains due to the fragmentation of production, the emissions induced by foreign trade have generated great concern (Meng et al., 2017; Michieka et al., 2013; Peters et al., 2011). If urban policies are merely designed to reduce air pollution emissions within the administrative boundaries, the so-called phenomenon "local reduction, overall rise" will ineluctably occur (Li et al., 2016, 2018). A large body of literature has proved that external trade exerts great impact on the emissions profile of urban economies, whose emission reduction goals are partly achieved by shifting their emission-intensive industries to other regions (Chen et al., 2017c; Cheng et al., 2018; Davis and Caldeira, 2010; Jiang et al., 2017; Li et al., 2017; Meng et al., 2016a;

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https://doi.org/10.1016/j.ecolind.2018.06.057
Received 25 April 2018; Received in revised form 11 June 2018; Accepted 27 June 2018
1470-160X/

Wang et al., 2018). For instance, Meng et al. showed that 44% of black carbon emissions related to goods consumed in Chongqing and more than 60% for Beijing, Shanghai and Tianjin occurred outside of the city boundary (Meng et al., 2017). Long et al. employed city-scale MRIO of Tokyo to evaluate emission responsibility and found that transportation sector accounted for the largest share of direct emissions in Tokyo while indirect emissions were dominated by energy supply, construction, private service sectors (Long and Yoshida, 2018). Meng et al. investigated the impact of trade on three particulate matter (PM) of different diameters concentrations in Beijing, demonstrating that half of the direct PM emissions were related with exports (Meng et al., 2016a). Jiang et al. analyzed the total pollution control cost transfer embodied in inter-provincial trade and the result showed that Tianjin and other developed metropolis have transferred the total air pollution to energy-rich undeveloped provinces through the consumption of pollution-intensive products from Shanxi, Inner Mongolia, Hebei and Henan (Jiang et al., 2017). Li and his colleagues found out that the majority large proportion of Beijing's mercury emissions were transferred to other regions by domestic and foreign imports (Li et al., 2017; Zhang et al., 2018).

The existing studies undoubtedly enable people to better understand the trade related urban air pollutant emissions. However, previous IO-based urban studies usually focused on air pollutant emissions embodied in trade in one specific year. Nonetheless, great changes in energy consumption, trade expansion and economic growth have taken place in urban economies during the past years (Al-Mulali and Ozturk, 2015; Lu et al., 2016). Hence, it is of great importance to investigate the historical temporal evolution pattern. In addition, research on the effects of factors such as trade structure on urban air pollutant emissions has been lacking.

To answer these questions, this study uses Macao, a typical urban economy, as a case to investigate how external trade reshapes the urban air pollution emission profile. As one of the two Special Administrative Regions, Macao has created an economic miracle. Thanks to its gaming and tourist industry, Macao's GDP increased from 5.33E + 04 million MOP in 2000 to 4.13E + 05 million MOP in 2013. In the meantime, its energy consumption has more than doubled (DSEC, 2000–2013b). As a consequence, in order to optimize its energy structure and satisfy its ever-increasing energy demand, Macao has imported large amounts of energy resources such as natural gas and electricity from other regions, with a total external trade volume of 4.98E + 05 million MOP (Lei et al., 2016). In regards to Macao's heavily dependence on external trade, many of the previous studies have investigated the trade related greenhouse gas emissions (Chen et al., 2017a; Chen et al., 2017b). However, few efforts have been made to explore trade's influences on Macao's air pollutant emissions. In addition, many studies have evaluated Macao's carbon emissions but research on air pollutants accounting has been lacking.

To fill these blanks, this study aims to: (1) establish a long time serial embodied emission intensity inventory of 5 main air pollutants (i.e. SO_2, PM_{10}, NMVOC, NO_X, CO) with regional and sectoral details by adopting the most updated multi-regional input-output database and 5 air pollutants emission satellite accounts; (2) evaluate the temporal and spatial evolution of Macao's air pollutants flows via external trade from 2000 to 2013 by combining Macao's bilateral trade data with emission intensity inventory; (3) reflect various trade factors' effects on embodied air pollution emissions induced by Macao. It is expected that the current research will propose feasible solutions to provide insights for urban air pollutant emissions from both local and global perspective.

2. Methodology and data sources

2.1. Embodied emission intensity database

Multi-regional input-output (MRIO) analysis is used to construct the long time serial embodied intensity inventory of 5 main air pollutants with high sector and country details (Chen et al., 2018a; Chen et al., 2018b; Meng et al., 2016b; Meng et al., 2018; Minx et al., 2009). Considering all the inputs and outputs, the physical balance of embodied emissions flows can be formulated as it is in the following equation in the following equation:

$$ap_i^s + \sum_{r=1}^{n}\sum_{j=1}^{m}\varepsilon_j^r z_{ji}^{rs} = \varepsilon_i^s x_i^s \tag{1}$$

where n and m correspond to the number allocated to one of the 188 different economies and one of the 26 different sectors analyzed in this study, respectively. ap_i^s denotes the direct energy-related air pollutant emission, z_{ji}^{rs} stands for the monetary value of trade selling from sector i in economy s to sector j in economy r, x_i^s denotes the output of sector i in economy s.

Subsequently, a matrix form of Eq. (1) can be expressed as:

$$\text{E} + \varepsilon\,\text{Z} = \text{E}\hat{X} \tag{2}$$

where $\text{E} = [ap_i^s]_{1\times mn}$, $\varepsilon = [\varepsilon_i^s]_{1\times mn}$, $\text{Z} = [z_{ij}^{sr}]_{mn\times mn}$, and $\text{X} = [x_i^s]_{1\times mn}$, ($\hat{X}_{mn\times mn}$ is the corresponding diagonal matrix)

Then, the embodied emission intensity matrix εcan be deduced as:

$$\varepsilon = \text{E}(\hat{X} - Z)^{-1} \tag{3}$$

2.2. Embodied air pollutant emissions accounting

When multiplying the trade data (imports and exports) with the corresponding embodied air pollutants emission intensity, the embodied air pollution in imports (*APEI*) and exports (*APEE*) can be obtained as follows:

$$APEI^M = \sum_s\sum_j\left(\sum_r\sum_i \varepsilon_{ij}^{rs} \times Im_j^{sM}\right) \tag{4}$$

$$APEE^M = \sum_s\sum_j\left(\sum_r\sum_i \varepsilon_{ij}^{rM} \times Ex_j^{Ms}\right) \tag{5}$$

in which Im_j^{sM} denotes Macao's imports from sector j in region s, while Ex_j^{Ms} stands for Macao's export of sector j to region s. The superscript M represents Macao.

The air pollutants emissions embodied in trade balance (*APEB*) can be expressed as:

$$APEB^M = APEI^M - APEE^M \tag{6}$$

Thus, the total embodied emissions (*TEE*) can be expressed as:

$$\text{TEE} = APEI - APEE + AP \tag{7}$$

where *APEI*, *APEE* and *AP* are the air pollutants emissions embodied in imports and exports, respectively. AP, stands for the direct air pollutants emissions. Goods and service are both included in external trade considering that gaming service industry plays the leading role in Macao's economy (Chen and Li, 2015). As data on service trade between Macao and its partners is unavailable, the global mean air pollutants emission intensity of the corresponding service industry is used to calculate embodied air pollution in service trade.

2.3. Dynamic regression analysis

In this study, the dynamic regression analysis is applied to investigate the relationship between economic growth and air pollutants emissions, which is useful for policies formulation to reconcile economic growth and environmental impacts. Referred to Cole et al. (2008) and Li and Lu (2010), a dynamic regression mode is established in this study to deeply dig into the correlation between the *TEE* (total embodied emission) and *Trade* (the ratio between trade volume and GDP), *Export*, *Import* and *GDPPC* (GDP per capita). The equation of linear regression is established below: