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Impacts of supply and consumption structure on the mercury emission in China: An input-output analysis based assessment

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ABSTRACT

In this paper, we quantified the enabled and embodied mercury emissions in China using income-based accounting (IBA) and consumption-based accounting (CBA). Combined with emission linkage analysis (ELA) and structural decomposition analysis (SDA), key sectors and socioeconomic determinants were investigated to understand the supply and consumption structure that affecting mercury emissions in China. ELA showed that 7 sectors were identified as key mercury emissions sectors in 2012. IBA and CBA revealed that mining and service sectors were major income-based mercury emitters, and construction and manufacture sectors were major consumption-based emitters. Fixed capital formation contributed 304.1 t of embodied mercury emissions, while employee compensation led to 182.4 t of enabled mercury emissions in 2012. The supply-side SDA indicated that, from 1997 to 2012, the primary input structure had a large contribution to the increase in mercury emissions. It had a greater impact on the mercury emission increase than the final demand structure based on the demand-side SDA. Economic structure change reduced the mercury emissions during the period from 2007 to 2012. Our research indicated that a more comprehensive knowledge of supply and consumption patterns of economic structure could help the government formulate better policies to control mercury emissions.

1. Introduction

Mercury, as a persistent and global contaminant, may cause huge damage to the aquatic ecosystems and human beings, due to its high toxicity and bioaccumulation in the environment (Chen et al., 2015; UNEP, 2013; Wang et al., 2014). In 2013, the Minamata Convention on mercury was adopted internationally to jointly control mercury emissions world widely (Ancora et al., 2016). More efforts were devoted to studying mercury emissions, especially from anthropogenic sources (Horowitz et al., 2014; Streets et al., 2005, 2011). Previous studies showed that China was the largest atmospheric mercury emitter in the world and thus it is particularly important for China to reduce the mercury emissions, especially the emissions associated with production activities (Pacyna et al., 2006, 2010; Pan et al., 2006; UNEP, 2013; Ye et al., 2015). Zhang et al. updated the mercury emission inventories of China and estimated that the mercury emissions to be continuously increasing from 356 t in 2000 to 538 t in 2010 (Zhang et al., 2015a). Wu et al. compiled a consistent series of China's atmospheric mercury emissions at the provincial level from 1978 to 2014 and estimated that mercury emissions increased from 147 t in 1978 to 530 t in 2014 (Wu et al., 2016).

However, economic sectors are not isolated, they link with each other as an intertwined network (Chen et al., 2017a). Mercury emissions arising from the production activity of one sector may be driven by another sector's activities throughout the whole supply chain or sale chain (Chen et al., 2017a). Thus, in recent studies, researches used consumption-based accounting (CBA), which is built based on environmentally extended input-output analysis (EEIOA), to evaluate the direct and indirect mercury emissions (Chen et al., 2017b; Davis and Caldeira, 2010; Davis et al., 2011; Feng et al., 2013; Guan et al., 2009; Li et al., 2016; Meng et al., 2015, 2016; Zhao et al., 2015). Some scholars calculated mercury footprints at

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the global level (Chen et al., 2016; Li et al., 2017a; Liang et al., 2015). At national level, Liang et al. conducted a top-down analysis on virtual atmospheric mercury emission networks in China and calculated embodied mercury emissions in China from 1992 to 2007 (Liang et al., 2013, 2014). Chen et al. analyzed China's energy-related mercury emissions in 2010 and revealed that over a quarter of China's direct mercury emissions from fuel combustion were attributed to the commodities exported to the foreign countries in 2010 (Chen et al., 2017a). At the city level, Li et al. analyzed the impact of trade on fuel-based mercury emissions based on EEIOA (Li et al., 2017b).

Previous studies estimated the embodied mercury emissions based on CBA, in which the Leontief demand-driven input-output (IO) model was used (Steininger et al., 2016). The current market-based economy places an emphasis on the consumption process, and it is the natural choice to discuss the consumption driving forces (Lenzen and Murray, 2010; Marques et al., 2012). However, governments also want to know the production-related mercury emissions driven by the value added (primary input) but not the final demand (Liang et al., 2016b; Zhang, 2010). In addition, people could consume more, only if they obtain more income. This could be achieved through the supply of primary factors of production (Marques et al., 2012). Income-based accounting (IBA), in which the Ghosh supply-push IO model is used, was conducted to reveal critical primary suppliers (Liang et al., 2016b). The application of IBA and CBA can help the policy-makers to reduce mercury emissions from both supply and consumption sides (Steininger et al., 2016; Xia et al., 2016). Given a more comprehensive analysis from two sides, we can reveal the mercury emissions from all economic activities and understand sectoral differences.

Meanwhile, identifying the causes of changes in mercury emissions is of great interest and important for the policy-makers. To solve this problem, a key method is decomposition analysis (DA) (Hoekstra and van den Bergh, 2002). Structural decomposition analysis (SDA) is one kind of DA (Ang and Zhang, 2000; Dietzenbacher and Los, 1998; Hoekstra and van der Bergh, 2003). SDA has been widely applied to assess the socioeconomic driving factors for energy, CO_2 emissions, air pollutants, and mercury emissions based upon the Leontief demand-driven IO framework (Guan et al., 2008; Liu et al., 2012; Meng et al., 2016), but it was rarely applied based upon the Ghosh supply-push IO framework (Liang et al., 2016b; Zhang, 2010).

The findings of SDA could help identify the socioeconomic drivers for mercury emission change at the macro level, but it could not identify the sectors with the greatest capacity for mercury emissions at the micro sector level. Mercury emission linkages analysis (ELA) yields insight about forward and backward mercury emission effects associated with a given sector. We can identify the key mercury emission sectors (KMES) by using ELA. It can give a deeper understanding and a systemic perspective on a sector's contribution to mercury emissions (Chang and Lahr, 2016).

In this study, we attempted to present the IBA based and CBA based mercury emissions analysis in China from 1997 to 2012 to assess the impacts of supply and consumption structure on mercury emissions. In addition, we conducted an emission linkage analysis (ELA) and IO-SDA to identify the sectoral differences and socioeconomic driving factors on mercury emissions from the perspective of both the supply and consumption sides. Some previous studies have attempted to combine the CBA and SDA to calculate the embodied mercury emissions in China. Our study extends the existing studies and is novel in three aspects: (1) We used IBA to calculate the enabled mercury emissions in China. Compared with the embodied mercury emissions estimated using CBA, we offered more comprehensive analysis about the impacts of supply and consumption structure on mercury emissions in China. (2) We decomposed the changes of China's mercury emissions by using SDA from both supply and consumption sides. (3) This is the first attempt to adopt ELA to identify the most responsible sectors for mercury emissions in China, and could provide a better analysis on these key mercury emissions sectors.

2. Methods and data

2.1. Supply-push IO model and consumption-driven IO model

Income-based accounting (IBA) and consumption-based accounting (CBA) were used in this paper to estimate enabled mercury emissions and embodied mercury emissions in China from 1997 to 2012, based on the environmentally extended input-output analysis (EEIOA), which can reveal the impacts of supply and consumption patterns on the mercury emissions respectively. The functioning of the IO framework can be captured by either the demand function (F) or value addition (V) function. From the IBA perspective, the exogenous variable employed in assigning emissions released is the value-added, while in CBA it is the final demand (Bogra et al., 2016; Steininger et al., 2016). We used the Ghosh supply-push IO model to conduct IBA, and the Leontief demand-driven IO model to conduct CBA. Technical details of this method can be referred from the previous literature (Bogra et al., 2016; Dietzenbacher, 1997, 2002; Ghosh, 1958; Guan et al., 2014; Leontief, 1936, 1970; Liang et al., 2016b; Miller, 2009; Minx et al., 2011; Rodrigues and Domingos, 2008; Rodrigues et al., 2006; Zhang, 2010). We provide a brief introduction here.

The Ghosh supply-push IO model (1) and the Leontief demand-driven IO model (2) can be expressed mathematically as:

$$t = V(I-B)^{-1}\left(\varepsilon^{d}\right)' \tag{1}$$

$$t = \varepsilon^{d}(I-A)^{-1}Y \tag{2}$$

where t is the total mercury emissions; ε^d is the direct mercury emission intensity; I is the identity matrix; $G=(I-B)^{-1}$ is the Ghosh inverse matrix; $L=(I-A)^{-1}$ is the Leontief inverse matrix; V is the value-added row vector; Y is the final demand column vector; and the notation ′ is the transposition.

Based on these two IO models, we can estimate the production-based, income-based and consumption-based mercury emissions of each sector. Production-based mercury emissions means the direct mercury emissions from production processes, which are the satellite account of the EEIOA. Income-based mercury emissions, which means the total downstream mercury emissions enabled by primary inputs of a sector, can be estimated from IBA. Consumption-based mercury emissions, which means the total upstream mercury emissions caused by the final demand of products, can be estimated from CBA (Liang et al., 2016b; Steininger et al., 2016). The specifications for IBA and CBA are given in Eq. (3) and Eq. (4), respectively:

$$S = \widehat{V}G\left(\varepsilon^{d}\right)' \tag{3}$$

$$C = \varepsilon^{d}L\widehat{Y} \tag{4}$$

where $\delta = G(\varepsilon^d)'$ denotes the total enabled emission intensity and its element δ_i could be referred to as the forward mercury emission multiplier of sector i; $\varepsilon = \varepsilon^d L$ denotes the total embodied emission intensity and its element ε_j could be referred to as the backward mercury emission multiplier of sector i (Zhang, 2010).