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Estimating inter-regional payments for ecosystem services: Taking China's Beijing-Tianjin-Hebei region as an example

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ABSTRACT

The inter-regional payments for ecosystem services (PES) is an important policy to promote regional ecological and environmental cooperation. However, the existing inter-regional PES standard in China may underestimate the value of ecosystem services and omit the value of transferred pollutants due to inter-regional trade. A reasonable framework of inter-regional PES standards is necessary for the policymakers, especially in Beijing-Tianjin-Hebei (BTH) region with the most serious environmental problem in China. This paper employed the method of environmental impact evaluation and multi-regional input-output model (MRIO) to build a framework of inter-regional PES estimation, which both contained the regional spillover value of ecosystem services and the regional transfer value of pollutants. Finally, we estimate the amount of inter-regional payment for ecosystem services within BTH region. The results indicated that the PES standards within BTH region were 13.8 billion yuan and 19.2 billion yuan from Beijing, Tianjin to Hebei province in 2012, which accounted for 0.77 % and 1.49 % of their GDP in 2012. These PES standards are effective for regional ecological and environmental cooperation within BTH region and a multi-dimensional marketization mechanism should be implemented to reinforce inter-regional payment for ecosystem services, which may pave the way for other regions or countries.

1. Introduction

One of the most important tasks that economists face in designing ecological or environmental policies is to evaluate the economic value of ecosystem services (ES) and implement the payments for ecosystem services (PES) (Pagiola and Platais, 2006; Farley and Costanza, 2010). PES refers to a volunteer transaction between the user and the supplier of ecosystem services, while a conditional payment is based on the ecosystem services generated by the natural resources management agreement between them (Wunder, 2015). Here, ES is a generalized concept that includes both environmental services, such as absorbing pollutants and purifying environment, and other services like life supporting, providing raw materials, recreation and aesthetic enjoyment. In China, PES will act as an important constitutional arrangement for the construction of eco-civilization and will be very helpful in protecting the natural environment and promoting regional ecological and environmental cooperation in China (Hu et al.,2019).

As an incentive mechanism aimed at encouraging ecosystem service suppliers to provide ecosystem services with positive externality or characteristics of public goods, PES is regarded as an application of Coase's theory to ecological and environmental policies (Coase,1960) and is introduced to address the market failure to account for externalities. PES schemes offer financial incentives in exchange for the maintenance of ES provision (Van Hecken et al., 2015a). PES has been adopted as a mechanism designed and implemented at an international level to drive political commitments, policies and measures (Angelsen et al.,2012). Besides it has also been adopted by several national governments through a number of initiatives, often with explicit links to policies (Singh et al., 2015). So far, PES has been widely discussed and examined by international scholars, focusing on the definition, subjects, objects and standards (Wunder, 2005).

One of the most popular definitions of PES was originally given by Wunder (2005) from the Center for International Forestry Research (CIFOR), who thought that PES usually involved four features: PES must be a voluntary behavior; ecosystem services can be clearly classified as a certain method of land use to ensure that ecosystem services

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are provided; there are at least one purchaser and one supplier of ecosystem services; and the supplier can receive PES only when he or she supplies ecosystem services (Wunder, 2005). Subsequently, some researchers expanded the content of PES (Mao et al., 2002; Muradian et al., 2010; Sommerville et al., 2009; Tacconi, 2012). Wunder's definition of PES has been widely criticized as too restrictive and normative (Muradian et al., 2010). In recent years, two main challenges to the concept of PES have emerged with one political and the other conceptual (Daniel et al., 2017).

The political challenge to PES was that it reflected a wider ideology of market environmentalism, emphasizing the commodification and marketization of ecosystem services (Kosoy and Corbera, 2010). The market view of resource management relied on harnessing self-interest through individual incentives and therefore risked ‘crowding out’ intrinsic motivations and pro-social behavior not based on instrumental rationality (Midler et al., 2015; Muradian and Rival, 2013). The inevitable ‘itemisation’ of ecosystem serviced as a precondition of their commodification in PES schemes was criticized as an ideological strategy for the neoliberalization of nature (Boisvert et al., 2013; Brockington, 2011; Peluso, 2012), just like the logic of ‘selling nature to save it’ (McAfee, 1999).

The conceptual critique held that most PES programs ‘did not satisfy the strict criteria of markets (high commoditization; high conditionality; voluntariness)’ (Muradian and Rival, 2013). First, making ES into commodities was often difficult, as most ES were either public goods or common pool resources, which needed significant organizational and political efforts and interventions to make them become tradable commodities (Muradian and Rival, 2013). Secondly, many PES cases failed to meet the conditionality criteria (Muradian et al., 2010). Thirdly, in many cases, the voluntary character of the transaction was not given (Kosoy et al., 2007). Furthermore, transaction costs in PES schemes were usually very high, which obviously contradicted the Coasean ideal of a market-based resolution of externalities. As the intermediaries played a crucial role in the process of setting up PES schemes, which made transaction costs increase (Vatn, 2010). The participants in PES are sellers and buyers. The sellers usually refer to ecosystem services suppliers. As the land use type can impact the quantity and quality of ecosystem services, sellers of PES are mostly land owners. The buyers can be divided into two types: the ecosystem services user, who is also referred to as *user payment*, and the third party representing the ecosystem services user, who is also referred to as *government payment* (Engel et al., 2008). In practice, the governments are the main participants of PES projects both in developed countries and developing countries (Schomers and Matzdorf, 2013). The objects of PES are activity types or ecosystem services. Changes in land use type will affect the ecosystem services by altering biodiversity, systematic ecological processes, and the environment (Ouyang and Zheng, 2009).

Among the related literatures about PES, most of them focused on optimization models for contract and payments design (Ajayi et al., 2012), ES mapping (Daily et al., 2009), spatial targeting for the optimal selection of ES providers (Schomers et al.,2015) and cross-farm cooperation incentives among ES providers (Parkhurst and Shogren, 2007; Wunder et al., 2008). However, they remained theorized in social and political terms, resulting in a weak understanding of the role of culture, agency, social diversity and power relations in the shaping of PES institutions and their outcomes (Van Hecken et al., 2015b). Then researchers started to consider PES as ‘political projects’ by offering an analytical tool for investigating power relations, political decisions, place specific ideas and social norms in the construction and operation of PES schemes (Daniel et al., 2017). Some scholars thought that the promised efficiency gains of PES were hard to demonstrate, and recommended conceptual modifications for PES from a hybrid institutional or ‘ecological economics’ perspective (Muradian et al., 2010).

The most difficult part of PES, both in theory and in practice, is the assessment of the economic value of ecosystem services and the establishment of the PES standard (Song, 2018). If the standard is too high, the buyer of PES can hardly afford the corresponding cost, which will be a huge burden on local governments. If it is too low, the seller of PES may not have the incentive to protect the ecosystem and the environment. Extensive literatures have focused on this issue, and there is a consensus that the PES standard should lie between the opportunity cost (lower limit) of protecting the ecosystem and the ecosystem services value (ESV) (upper limit) (Wunder, 2007; Ribaudo and Savage, 2014). During the implementation procedure, many PES projects chose to set up standards in line with the opportunity cost, such as the Grain for Green Project (GGP) and the Grassland Ecological Protection Project (GEP) of China (Li and Liu, 2010; Lin et al., 2017), the Cropland Retirement Project (CRP) and Environmental Quality Incentive Project (EQIP) of America (Claassen et al., 2008), and additional projects in Costa Rica, Mexico, etc. (Kalacska et al., 2008).

However, opportunity cost measures the revenue forgone by using the next best alternative use, which is difficult to be precisely quantified. For example, a local government will have various alternative uses if not protecting its ecosystem, such as developing pollution-intensive industries, building commercial apartments, or constructing any other infrastructures, etc., so which is the next best alternative use and how to calculate all the possible revenue from this use? Besides, the opportunity cost is the lower limit of PES, which underestimates PES standard and omits the value of ecosystem services themselves, especially the value of transferred pollutants due to inter-regional trade (Zhao et al., 2015; Yang et al., 2018). Because the primary aim of PES is to correct the market failure of externalities in the field of ecology and environment (see Appendix A in Supplementary material), it is necessary to take the value of ecosystem services spillover (positive externalities) and the value of trade-embodied pollutants (negative externalities) into account to set up more reasonable PES standards. Fortunately, there were some existing researches valuing the trade-embodied pollution emissions, which provided significant perspective for the estimation of the inter-regional PES (Wang et al., 2017; Jiang et al., 2017; Xia et al., 2018)

Our major contribution to existing studies is to develop a formula calculating inter-regional PES standards, based on the regional spillover value of ecosystem services and the value of regional transferred pollutants. With this formula, the calculation of PES standards will not need to measure the opportunity costs anymore. The next section introduces the evolution of PES policies and practices in China, followed by a section presenting the framework of inter-regional PES estimation. Then, we describe a detailed case and address the application to Beijing-Tianjin-Hebei (BTH) region with empirical analysis. The final section discusses the model results and draws some conclusions.

2. Evolution of PES policies in China

The evolution of China’s PES policies can be summarized by four characteristics: policy status becoming more important, areas involved in PES becoming much more comprehensive, more stakeholders involved in PES, and more reasonable compensation principles.

First, the policy status is becoming more important. The statement of PES did not emerge in any laws or policy files but instead was implicitly embedded in environmental regulations from 1978 to 2004, rewarding actors with better performances in protecting the forest and grassland. In *China’s 11th Five-Year Plan* in 2005, the Chinese government proposed to build a PES mechanism based on the principles that “the person or firm who exploited natural resources or polluted the environment should be responsible for its protection, and the person or firm who benefited from better ecosystems and natural environment should pay the benefit.” Since then, a series of specific policies related to PES has been implemented, such as *Guidance on implementation of PES pilot work* (in 2007), *Measures (Pilot) of transfer payment in national key ecological functional zones* (in 2009), *General Office of the State Council’s opinion about acceleration of PES* (in 2016), *Treasury Department’s guidance on establishing and accelerating long-run mechanism* *of PES and protection in the Yangtze Economic Zone* (in 2018), and *Action plan for establishing a marketized and multidimensional mechanism of PES* (in 2019).

Secondly, areas involved in PES are becoming much comprehensive, ranging from the only forest, grassland and mine resources to also including important areas, such as Prohibited Development Zones (PDZs) and Key Ecological Functional Areas (KEFAs). The number of cities and counties that can receive transfer payments in KEFAs increased from 451 in 2010 to 816 in 2017. In addition, the PES of ecological redline and the comprehensive PES of Qinghai Sanjiangyuan National Park have begun to be actively studied and explored. The PES of the river basin has been extended from intra-province to inter-province. To date, 17 provinces have already implemented intra-province PES of river basins. Many river basins, such as Xin'anjiang, Jiuzhoujiang, Tingjiang-Hanjiang and Dongjiang, have signed inter-regional PES agreements upstream and downstream of inter-province river basins. After the implementation of the *Ocean ecological civilization construction act (2015–2020)*, many places such as Shandong, Tianjin and Xiamen have built ocean PES mechanisms, emphasizing sea pollution abatement. Shandong and Henan Provinces have begun to explore the PES of air quality.

Thirdly, more stakeholders are involved in PES. As PES methods in China have changed from mainly focusing on vertical PES to combining vertical and inter-regional PES, utilizing marketized and multi-dimensional tools and fiscal transfer payments by the central government. More and more stakeholders are participating in PES, including government and related sectors at all levels, as well as many firms and individuals.

Finally, the compensation principles become more reasonable. China's PES practices followed by the polluter pays principle in the 1980s were confined to direct production costs or ecological construction costs for ecosystem and environmental protection. Since 2005, the beneficiary pays principle has been reflected in the PES practices, which means that the party who developed should protect the environment, and the party who benefited from the environment should pay PES, where ecological protection costs, opportunity costs of development, and ecosystem services value have been taken into account.

In the past decades, great achievements have been made for China's PES research, policies and practices; however, there are still some problems to be addressed. For example, there are few inter-province or inter-regional PES cases that have been established, which will prevent effective regional environmental cooperation. There is still no unified formula to calculate PES standards; and there are no comprehensive PES cases taking both integrative ecosystem services and main pollutants interregional transferring into account.

Since China's reform and opening-up in 1978, the PES policy and practices have been continually optimized to facilitate environmental protection (Wang et al., 2019a, 2019b). However, there are still some shortcomings preventing neighboring areas from constructing effective cooperative governance mechanisms based on the principles of sharing costs and benefits, known as cooperative governance (Wang et al., 2019a, 2019b). Whereas the synergetic development of the BTH region is one of China's national strategies, and the ecological and environmental cooperation within this region is deemed as the most important issue due to severe environmental problems, such as the cross-boundary haze and water pollution (Huang and Luo,2017). Measuring the amount of inter-regional PES within BTH region will be helpful for regional ecological and environmental cooperation (Fu et al., 2018; Song et al., 2018).

3. The framework of inter-regional PES estimation

An ideal institution for PES usually meets four principles (Lin et al., 2019). The first principle is parity, which means that the government rank or administrative level in PES must be the same, for example, province/state-to-province/state or city to city. If there is no such parity, for example, one government is subject to or is less powerful than another, then the amount of PES would tend to be underestimated or overestimated, and PES enforcement would be affected. The second is measurability, which means that the economic value of an ecological service can be measured as precisely as possible. The third principle is additionality. Similar to a typical consumer's behavior, paying money and receiving goods from shops, one local government will also pay PES to another local government; meanwhile, it must receive corresponding additional ecological services from other regions or transfer its pollutants to other regions. The final principle is conditionality. Whether a local government can receive PES from another must depend on some conditions, one of which is that the local government truly takes positive measures to protect its ecology and environment, rather than the local government doing nothing since it naturally possesses a good natural ecological environment. Taking this into account, the exact amount of PES should not be set up merely according to the economic value of the ecological services offered by some local regions for a certain period. To what extent the local government takes positive action to protect its ecological environment must also be taken into account.

3.1. Models to calculate the standards of PES

Existing studies about estimation of PES usually employ pure econometric model based on willing to accept (WTA) (Kang et al., 2019), arithmetic model aiming to evaluate environmental benefits generated from certain types of ecosystems (Ranjan, 2019), or opportunity cost method to calculate the horizontal transfer payment (Liu et al., 2019). However, few of them can construct a consistent model to calculate the standards of PES, taking both the positive externality (ecosystem services spillover effect) and the negative externality (regional transfer of pollutants) into account, which will be our main contribution in this paper.

Taking two regions as an example, region r and region s, $PES_{s\text{-}r}$ represents the amount of money that region s pays to region r.

$$PES_{s-r} = VESS_{r-s} + VPS_{s-r} \tag{1}$$

where $VESS_{r\text{-}s}$ is the value of the ecosystem services that spills over from region r to region s and $VPS_{s\text{-}r}$ is the value (also called abatement cost) of the pollutants transferred from region s to region r.

3.1.1. Calculating the value of VESS

The value of the ecosystem services between region r and region s are calculated by the following equation.

$$VESS_{r-s} = \frac{1}{1+M_r} \times ESV_r \times \beta_r$$
$$M = 1, 2, 3 ... N; \; 0 < \beta_r < 1 \tag{2}$$

where M_r is the number of regions adjacent to region r. Here, we suppose that region s is one neighbor of region r, which can share the ecosystem services of region r equally with region r and other neighbors of region r. ESV_r is the ecosystem services value of region r, β_r represents to what extent region r has tried to protect its ecosystem, where $\beta_r = 0$ means there are no policies to protect the ecosystem in region r, and $\beta_r = 1$ means region r has tried its best to protect its natural ecological environment. Beijing, Tianjin and Hebei have two, two and seven neighboring regions, respectively; therefore, M for Beijing, Tianjin and Hebei are 2, 2, 7.

Chinese central government released a green development assessment guide for each province in December 2016 (National Development and Reform Commission (NDRC), 2016), which contains a green development indicator (GDI) and six sub-indicators: resource usage, environment treatment, environment quality, ecosystem protection, growth quality and green life. Both the GDI and its 6 sub-indicators have a full score of 100 according to assessment guide.

Here, we employed two sub-indicators, environmental treatment and ecosystem protection, in our paper to measure the extent to which the local government positively protects its ecosystem and natural environment. The first assessment report of green development for each province has been released at the end of 2017, containing the scores of the above-mentioned two sub-indicators for Beijing, Tianjin and Hebei.

To get the value of β, we have,

$$\beta_r = \frac{(G_r^{env} + G_r^{eco})/2}{100} \tag{3}$$

Here, G_r^{env} and G_r^{eco} are province r's scores of sub-indicators, environmental treatment and ecosystem protection. Each province's scores can be found in the released report. We use the arithmetic average of the above two scores (divided by 100) to represent region r's β value. After calculation, the β value of Beijing, Tianjin and Hebei are 0.85, 0.74 and 0.80, respectively.

To calculate ESV_r, we divided the ecosystem of region r into 6 categories based on various types of land use, including cropland (*ES1*), forest (*ES2*), grassland (*ES3*), shrubland (*ES4*), wetland (*ES5*), and water *(ES6*).

$$ESV_r = \sum_{k=1}^{6} ES_{rk} \times P_k \tag{4}$$

where ES_{rk} is the area of ecosystem category k in region r. P_k indicates the economic value of per unit area of ecosystem category k.

3.1.2. Calculating the value of VPS

For $VPS_{s\text{-}r}$, we employ the multi-regional input-output Model (MRIO), calculating the number of net pollutants transferring from region s to region r and then estimating the value of these pollutants. The MRIO can describe the industries' interactions and the relationships between the consumption of the final goods and the total output among all the regions with a multi-regional input-output table (Miller and Blair, 2009; Wiedmann et al., 2011). Combining the MRIO and the resources and environment data enables us to reveal exactly how much resources are depleted and how many pollutants are emitted by other regions due to one specific region's final goods consumption (Feng et al., 2013; Peters, 2008; Su and Ang, 2011; Zhang et al., 2018). Suppose that there are n production sectors and m regions, r and s are regions, and i and j are the production sectors. According to the identity of MRIO, we have

$$x_i^r = \sum_s \sum_j z_{ij}^{rs} + \sum_s y_i^{rs} + e_i^r \tag{5}$$

where, x_i^r is the total output of sector i in region r, which is a $n \times 1$ matrix; z_{ij}^{rs} denotes part of output of sector i in region r assigned to sector j in region s as input, which is a $n \times n$ matrix; y_i^{rs} denotes part of output of sector i in region r assigned to region s as final goods consumption, which is a $n \times m$ matrix; and e_i^r is the export of sector i in region r.

Let $a_{ij}^{rs} = z_{ij}^{rs}/x_j^s$ denote the direct consumption coefficient; then, Eq. (4) can be written as follows:

$$x_i^r = \sum_s \sum_j a_{ij}^{rs} x_j^s + \sum_s y_i^{rs} + e_i^r \tag{6}$$

Then, let $X = (x_i^r)$, $Y = (y_i^{rs})$, $E = (e_i^r)$, so Eq. (5) can be written by

$$X = AX + Y + E \tag{7}$$

Eq. (5) can, therefore, be transformed as follows:

$$X = (I - A)^{-1}(Y + E) \tag{8}$$

The output X induced by domestic consumption and export can be expressed by

$$X = (I - A)^{-1}P \tag{9}$$

where I is an identity matrix, and $(I - A)^{-1}$ is the Leontief's inverse matrix in MRIO. $P = Y+E$ is a column matrix combining domestic consumption and exports. Let $L = (I - A)^{-1}$, whose element l_{ij}^{rs} denotes the output of sector i in region r consumed directly and indirectly by sector j in region s per unit of final goods.

Let $F^r = (f_i^r)_{n\times1}$, and $f_i^r = g_i^r/x_i^r$ denote the pollution emissions per unit of output for sector i in region r (ton/yuan), where g_i^r is the quantity of pollution emissions for sector i in region r.

Therefore, we have

$$E_{r-s} = F^r L P^s \tag{10}$$

$$E_{s-r} = F^s L P^r \tag{11}$$

Here, $E_{s-r} = (e_{ij}^{sr})_{mn\times mn}$, where e_{ij}^{sr} measures the pollutant emissions transferred from sector j in region r to sector i in region s due to the consumption and exports of region r. Then, we can obtain $VPS_{s\text{-}r}$ as following,

$$VPS_{s-r}^t = v_r^t \times \frac{E_{s-r}^t}{\eta^t} \tag{12}$$

Where t represent pollutant (SO_2, NO_x, COD and NH_3-N); v_r^t *is* pollutant t's emission tax rate in region r, indicating the tax required for each unit of pollutant t. VPS_{s-r}^t represent the monetary value of transferred pollutant t from region s to region r.

3.2. Data sources

The area of various ecosystems in Beijing, Tianjin and Hebei are directly cited from Lin et al. (2019). The ecological service value per unit area of various ecosystems are derived from previous estimations of Costanza et al. (1997) and Groot et al. (2012). Here, we adopted the average values of the ecological service value per unit area from the above researches due to the lack of referable values in China, of which are transformed into the value of 2012, as shown in Table 1.

The multi-regional input-output (MRIO) table of 2012, covering 42 sectors and 31 provinces, was produced by Dr. Yu Liu from Chinese Academy of Sciences based on the latest provincial input-output table (National Bureau of Statistics, 2016). A hybrid technique based on maximum entropy and dual-constrained gravity models was employed to trace intersectoral trade flows between each province in the process of the MRIO compilation (Robinson et al., 2001; Zhang et al., 2012), and the Chenery-Moses model was used to construct the inter-regional trade matrix (Moses, 1955). To adjust the MRIO table and make it coincide with China's national IO table, a kind of balance adjustment with the blocking method was used to control it (Henderson, 1955). We integrated 28 provinces other than Beijing, Tianjin and Hebei into one region named "rest of China" and integrated the 42 sectors into 30 sectors in this MRIO table. This paper employed a pollutant emission inventory of the year 2012, including the emission data of sulfur dioxide (SO_2), nitrogen oxides (NO_x), chemical oxygen demand (COD) and ammonia nitrogen (NH_3-N) in 30 sectors and 4 regions. These four

Table 1
The areas and ecological service value per unit area of BTH's each land type in 2012.

Land type	Areas (10^4 ha)			The ecological service value per unit area (yuan/ha)		
	Beijing	Tianjin	Hebei	Costanza et al.[a]	Groot et al.[b]	Mean
Cropland	34.4	76.8	1059.7	830.1	–	830.1
Forest	109.8	11.6	738.1	8743.6	10821.9	9782.8
Grassland	36.2	15.7	729.8	2093.4	19565.3	10829.4
Shrubland	4.9	0.2	39.3	4373.3	15193.6	9783.5
Wetland	0.9	0.9	3.3	133409.5	175017.7	154213.6
water	2.5	15.2	48.7	76680	29078.8	52879.4

Note: a) all the original service values' data derived from Costanza et al. (1997) were calculated by 1994 $, which here is transformed into 2012 $ and then changed into yuan RMB, using the 2012 exchange rate of 1 US $ = 6.3 yuan RMB; b) the mean values of forest and grassland derived from Groot et al. (2012) are used to represent the value of shrubland.

Table 2
The Conversion coefficients to PE and tax rate of each pollutant within BTH region.

Pollutants	Conversion coefficients to PE	Types	Tax rate (yuan/PE)			
			Nation	Beijing	Tianjin	Hebei[a]
SO_2	0.95	air	1.2 ~ 12	12	10	4.8 ~ 9.6
NO_x	0.95					*(avg. 7.2)*
COD	1.0	water	1.4 ~ 14	14	12	5.6 ~ 11.2
NH_3-N	0.8					*(avg. 8.4)*

[a] Note that the tax rate in Hebei is different according to environmental management needs, and we take the average value as Hebei's uniform value of tax rates for calculating *VPS*.

pollutants have become officially mandatory control pollutants in China's National Total Emission Control (NTEC) policy since 2006, which can represent China's situation of air and water pollution (Zhang et al., 2015). This pollutant emissions inventory was derived from the China Environmental Statistics (CES) database. Noted that both the MRIO table and emission inventory were used in our previous researches (Zhang et al., 2018, 2019).

To simplify the discharge fee of various pollutants, China's Ministry of Environmental Protection (MEP) designed a new measure named "*pollutant equivalent* (PE)", which allows aggregating different types of pollutants according to their environmental and health impacts by assigning a specific coefficient representing their respective damage to each pollutant. Here, the conversion coefficients of each pollutant to PE are shown in Table 2. In other words, per kg PE equal to 0.95, 0.95, 1 and 0.8 kg of SO_2, NO_x, COD and NH_3-N based on the impacts of individual pollutant on air quality or public health (Zhang et al., 2018). On the other hand, according to the *law of environmental protection tax of China* (Standing Committee of the Twelfth National People's Congress of China, 2016), the tax amount for each PE of atmospheric pollutants and water pollutants are among 1.2 ~ 12 yuan and 1.4 ~ 14 yuan, respectively. Each province can determine local specific tax amount within this scope according to actual conditions. Because the BTH region is the most polluted region in China, so three provinces, Beijing, Tianjin and Hebei, all significantly increased their local tax rate of air pollutants (SO_2 and NO_x) and water pollutants (COD and NH_3-N) (Table 2).

4. Empirical analysis

4.1. Ecosystem services regional spillover value within BTH region

Fig. 1 showed the ecological service values (ESV) of Beijing, Tianjin and Hebei in 2012, which were 18.1 billion yuan, 12.9 billion yuan and 194.7 billion yuan respectively, accounting for 8.0 %, 5.7 % and 86.2 % of the total ESV within BTH region. Hebei Province, as the largest area in this region, provides more than 85 % of the ESV in the entire region with its abundant prairie resources in the north and the Taihang Mountain in the west. While Beijing and Tianjin, as two municipalities, hold an ESV that is less than 15 % of the entire region due to their small size (only 15 % size of Hebei Province). In terms of ecosystem types, forests and grasslands are the main ESV providers, each providing 37 % of ESV for the entire region. In addition, the waters, distributed in the coastal provinces of Tianjin and Hebei, also donate 16 % of the total ESV. As the most water-deficient city in China, Beijing provides its ESV mainly relying on the forest in the northwest mountainous area.

Fig. 2 showed the ecological service value spillover (VESS) among Beijing, Tianjin and Hebei Provinces. Overall, Hebei was the main ESV outflow province within BTH region. It provided a total ESV of 38.9 billion yuan to Beijing and Tianjin, but also received a total ESV of 8.3 billion yuan from Beijing and Tianjin, with a net ESV outflow of 30.6 billion yuan. Tianjin, as a net ESV inflow province, provided a total ESV of 6.4 billion yuan to Hebei and Beijing, but also received a total ESV of 24.6 billion yuan from Beijing and Hebei, with a net ESV inflow of 18.2 billion yuan. Beijing was also a net ESV inflow province within BTH region, with a net ESV inflow of 12.4 billion yuan.

4.2. Value of pollutants transferred due to regional trade within BTH region

The total emissions of SO_2, NO_x, COD, and NH_3-N within BTH region in 2012 were 996 thousand tons (kt), 1237 kt, 941 kt, and 51 kt, respectively. For the production-based, Hebei emitted the most pollutants, 72.8 percent to 78.9 percent of the four pollutant emissions within BTH region. However, for Beijing, it was 9.3 percent to 11.5 percent, and for Tianjin, which was slightly more than Beijing, it was 11.2 percent to 16.4 percent. For the consumption-based, Hebei also emitted the most pollutants, 63.9 percent to 69.7 percent of the four pollutant emissions within BTH region. For Beijing, it was 14.9 percent to 17.8 percent, and for Tianjin, it was 15.4 percent to 19 percent. In all, the pollutant emissions from the production-based were greater than those from the consumption-based for Hebei; however, it was different for Beijing and Tianjin, where the pollution emissions from the consumption-based were much greater than those from the production-based. This means that Beijing and Tianjin transferred their pollutants to Hebei through purchasing pollution-intensive goods made in Hebei. We calculated the ratio between the pollutant emissions from the consumption-based and the production-based for Beijing, Tianjin and Hebei irrespective of the degree of pollution transfer. If the ratio was larger than 1 for a region, it meant that that region transferred its pollution to other regions, and if the ratio was less than 1 for a region, it meant that this region suffered from pollution transferred from other regions. As a result, the range of ratios for these 4 types of pollutants in Beijing, Tianjin and Hebei is 1.5–1.8, 1.2–1.4 and 0.9, respectively. Therefore, both Beijing and Tianjin transferred their pollution emissions to Hebei, and compared to Tianjin, Beijing transferred more pollution emissions to Hebei.

These four pollutants were transferred among Beijing, Tianjin and Hebei, as shown in Fig. 3. From the perspective of the production-

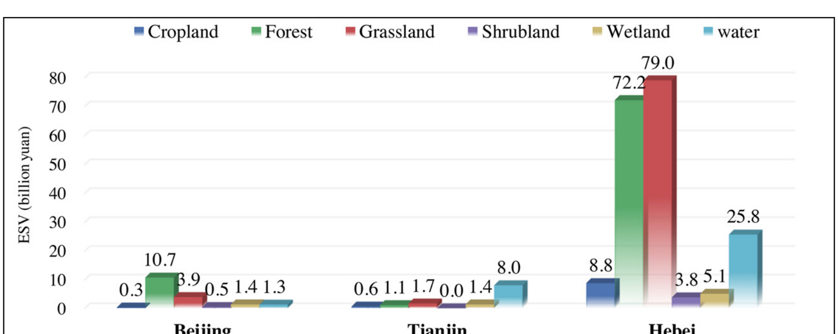

Fig. 1. The ecological service values of Beijing, Tianjin, Hebei by ecosystem types in 2012.

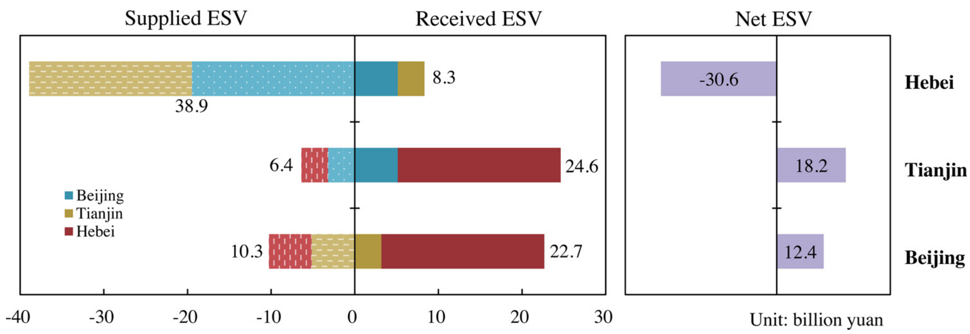

Fig. 2. Regional spillover of VESS within BTH region in 2012.

based, Tianjin and Hebei undertook a relatively higher share of pollution emissions for other provinces of China than did Beijing, with 13 percent to 18 percent, 13 percent to 16 percent, and 9 percent to 10 percent, respectively. From the perspective of the consumption-based, Beijing transferred the highest share of pollution emissions to other provinces, amounting from 40 percent to 50 percent. For Tianjin, it was 27 percent to 37 percent, and for Hebei, it was 1 percent to 3 percent. Overall, the pollution emissions that Hebei undertook for other provinces were much more than it transferred to other provinces. The emissions of SO_2, NO_x, COD, NH_3-N that Hebei undertook for other provinces were 99 kt, 111 kt, 87 kt and 5 kt higher, respectively, than the emissions that Hebei transferred to other provinces. However, the pollution emissions that Beijing and Tianjin transferred to other provinces were much greater than those that they undertook for other provinces. The emissions of SO_2, NO_x, COD, NH_3-N that Beijing transferred to other provinces were 73 kt, 26 kt, 78 kt and 32 kt higher, respectively, than those that it undertook for other provinces. The emissions of SO_2, NO_x, COD, NH_3-N Tianjin transferred to other provinces were 47 kt, 40 kt, 2.7 kt and 2 kt higher, respectively, than those that it undertook for other provinces (Fig. 4).

During the course of regional trade within BTH region, developed regions (such as Beijing and Tianjin) usually transfer large amounts of pollution emissions to less developed regions (such as Hebei) through goods and services consumption. Fig. 5 shows the main pollutant emissions transferred among Beijing, Tianjin and Hebei. For the regional trade within BTH region, Hebei was the only province with a net inflow of pollutant emissions, and both Beijing and Tianjin transferred pollution emissions to Hebei. For air pollution, there was a net inflow of 64 kt of SO_2 and 69 kt of NO_x transfer to Hebei from Beijing, 65 percent and 62.3 percent of Hebei's total net inflow of SO_2 and NO_x, respectively. All other residual parts of Hebei's total net inflow of SO_2 and NO_x came from Tianjin. For water pollution, Beijing and Tianjin contributed nearly fifty percent of the net inflow of COD and NH_3-N to Hebei.

According to Eq. (12), we calculated the net transfer value of trade hidden pollutant emission referring to the tax rate of each pollutant and obtained the net trade-induced VPS of four pollutants among provinces. According to the results (Fig. 5e), Beijing had a total outflow VPS of 1636 million yuan, among which 1394 million yuan VPS was transferred to Hebei through trade, accounting for 85 %, indicating that Beijing needed Hebei to bear 1394 million yuan pollution control expenses; while 242 million yuan VPS was transferred to Tianjin, accounting for 15 %. Tianjin also transferred a VPS of 976 million yuan to Hebei during the trade with Hebei, indicating that Tianjin needed Hebei to bear 976 million yuan for pollution control. In the process of trade with Beijing and Tianjin, Hebei Province incurred a total cost of 2371 million yuan for pollution control.

4.3. The PES standards within BTH region

According to the above results, Beijing and Tianjin benefited from the positive externality of BTH, receiving 12.4 billion yuan and 18.2 billion yuan net VESS from Hebei, respectively. Additionally, they also benefited from the negative externality of BTH, transferring a large number of pollutants to Hebei Province, which needs Hebei to pay additional 2.4 billion yuan for removing pollutant emissions caused by consumption of Beijing and Tianjin. Considering that Hebei has provided above ecological services for the other two cities, for the sake of fairness, this paper recommends that the standard of PES to Hebei province is set at 33 billion yuan within BTH region. Specifically, Beijing and Tianjin should pay 13.8 billion yuan and 19.2 billion yuan respectively to Hebei province for ecological services (Fig. 6).

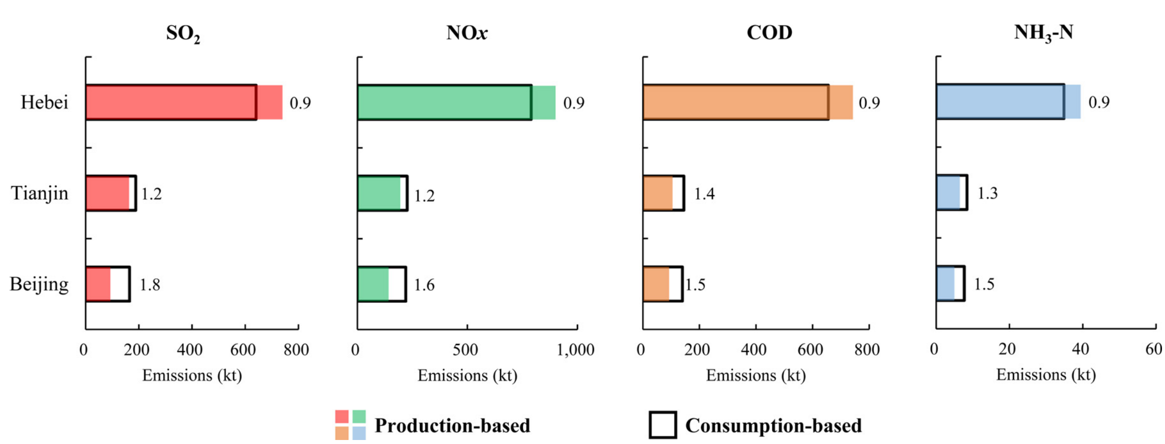

Fig. 3. Pollution emissions from production-based and consumption-based within BTH region (2012). Note that the number on the right side of this bar chart is the ratio between pollution emissions from the consumption-based and from the production-based, with a number larger than 1 indicating that emissions from the consumption-based were more than from the production-based, and vice versa.

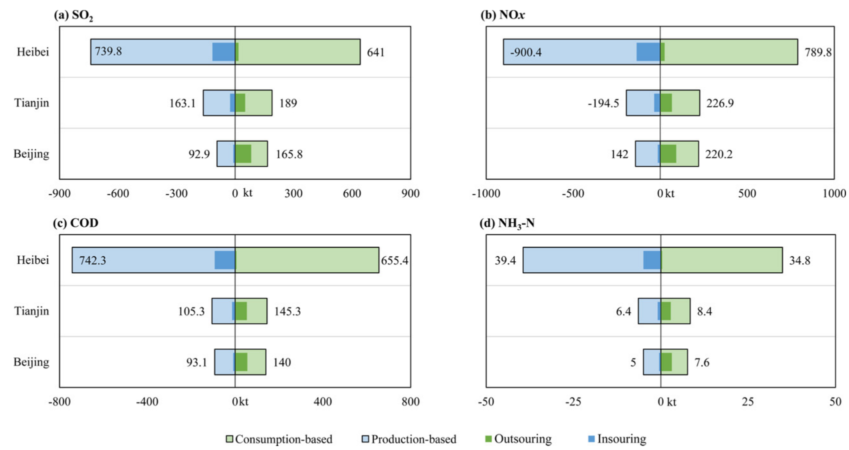

Fig. 4. Pollutant emissions transferred from BTH to other provinces and the share of total emissions emitted in 2012.

5. Discussion and conclusion

It was pointed out in China's *overall plan of ecological civilization system reform* that the water conservation area (WCA) within BTH region should carry out inter-regional PES mechanisms. *Cooperative development outline for the areas around Bo Hai* also encouraged relative regions to build up inter-regional PES institutions, launching a pilot project of inter-regional PES between ecologically protected areas and beneficial areas of river basins. To date, inter-regional PES mechanisms, vertical PES accompanied by inter-regional PES in the forms of money and technique, have been established between the city of Beijing and Zhangjiakou, northwest of BTH region. During the period of 2009–2016, ecological fiscal transfer from the central government to Zhangjiakou increased from 0.19 billion yuan to 0.95 billion yuan, and counterpart funding from local governments (Hebei Province and city of Zhangjiakou) increased from 23 million yuan in 2009 to 53 million yuan in 2015 (Environment Daily of China, 2018). In 2016, coordinated by China's Ministry of Environment Protection (MEP) and Ministry of Finance (MOF), Hebei and Tianjin signed the *Agreement of inter-regional PES upstream and downstream of the Luan River to Tianjin*, in which Hebei and Tianjin should co-establish environmental compensation funds, each contributing 0.1 billion yuan per year from 2016 to 2018. According to this agreement, Hebei should ensure and improve the water quality of the Luan River through non-point-source pollution abatement. If the water quality achieves or surpasses the established annual target, Tianjin will transfer all the funds in that year to Hebei Province, besides China's central government will reward Hebei Province 0.3 billion yuan at most per year depending on the detailed water quality of the *Luan River* to Tianjin for pollution abatement. In 2018, Hebei and Beijing signed the *Agreement of inter-regional PES for the WCA of the Chao and Bai River Basin upstream of the Miyun reservoir (2018–2020),* according to which, water quality and behaviors in the upstream would be examined. Beijing had already paid 0.2 billion yuan in advance to Hebei in 2018 and would audit the account in 2019 by targets achieved. At the same time, Beijing and Hebei will launch a pilot project of integrated environmental protection at the upstream of the *Miyun reservoir*.

The PES of the river basin within BTH region did transform certain amounts of money into environmental pollution abatement. As the water quality of the river basin was improved in the short term, many tasks appeared at the same time, especially the fiscal burdens and subsequent social responsibilities for the upstream area of the river basin. To protect the water resources of Beijing and Tianjin, which lies downstream of the river basin, the cities of Chengde, Zhangjiakou and

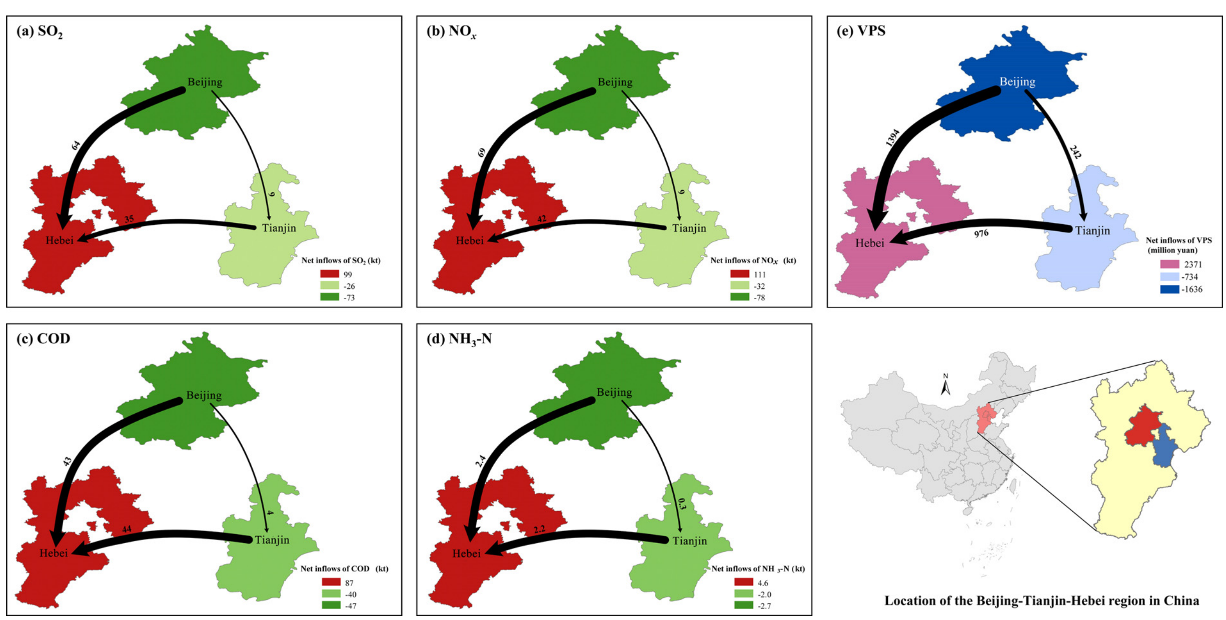

Fig. 5. Net trade-induced pollutants emissions and related VPS transfers within BTH region in 2012. Note that the size of Beijing, Tianjin and Hebei in (a)–(e) does not represent the actual area.

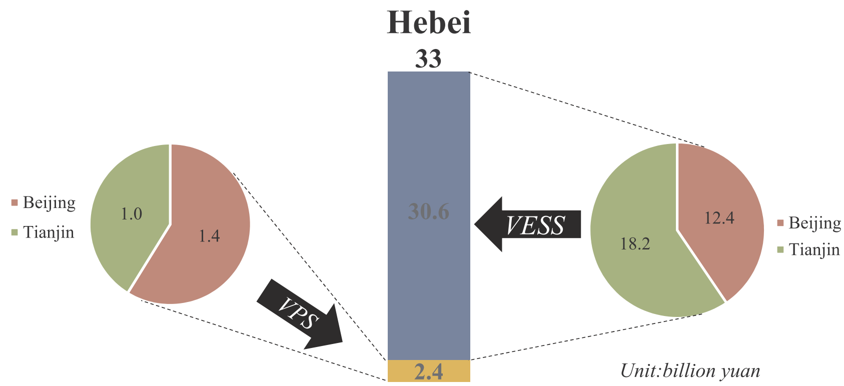

Fig. 6. The PES standards from Beijing and Tianjin to Hebei.

Tangshan, etc. in Hebei province have invested dozens of billion yuan (Economic Information Daily, 2018). For the regions that are adjacent to each other and interact in the field of economic and social development, for example the BTH region, its ecosystem and natural environment will be necessarily affected by the comprehensive environmental governance of its neighboring regions. Therefore, setting a reasonable standard and carrying out inter-regional and comprehensive PES can incentivize all of the stakeholders to effectively protect regional ecological environment. In 2012, the Gross Domestic Product (GDP) of Beijing, Tianjin and Hebei were 1.79 trillion yuan, 1.29 trillion yuan and 2.66 trillion yuan (National Bureau of Statistics of PRC (NBS), 2013), respectively. According to our evaluation, Beijing and Tianjin should pay 13.8 billion yuan (0.77 percent of Beijing's GDP) and 19.2 billion yuan (1.49 percent of Tianjin's GDP) to Hebei as the inter-regional and comprehensive PES. Together Hebei should receive 33 billion yuan (1.13 of Hebei's GDP) from Beijing and Tianjin for PES. However, in practice, both the fiscal transfer from the central government and the PES of the river basin paid by Beijing and Tianjin were far less than this number.

Therefore, three policy suggestions are recommended. First, Beijing and Tianjin should pay inter-regional PES to Hebei annually according to the spillover value of ecosystem services from Hebei and the transferred value of main pollutants to Hebei. Moreover, the annual PES standards should be flexible, and maybe a dynamic model framework of inter-regional PES with constantly updated parameters referring to environmental and economic indicators should be built by the central or regional government. Secondly, more compensation products, such as carbon trade and water permit trade, and more compensation methods, such as money, projects and techniques, should be well developed to eventually build multidimensional and marketized inter-regional PES mechanisms within BTH region. Thirdly, the inter-regional PES system of China should be further integrated and modified. Currently, there are different types of inter-regional PES projects in China, including forest, air quality, water quality and so on, most of which are interacted with each other. For example, water quality of a certain river basin will be affected by forest and soil conservation, air pollution, water pollution, etc. There exists double calculation issue without integrating these PES projects into one synthetic and comprehensive PES project. Besides, the Ministry of Environmental Protection of the People's Republic of China (MEP) was renamed by the Ministry of Ecology and Environment (MEE) in 2018, which to a certain degree implied that the main functions or duties of environmental agencies have expanded from pollution abatement to taking the whole ecosystem into account. Then, as this paper revealed, PES system should also be modified, including both ecosystem services spillover and transferred environmental pollution.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ecolecon.2019.106514.

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