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Key Points:
- Strengthening current environmental protection tax (EPT) to reduce household income tax is the most efficient way to reduce air pollution
- To reduce more emissions, using EPT revenues to invest in solar power, as well as reduce household income tax is the second-best option
- There is no double dividend if the EPT tax revenue is compensated by reducing enterprise income tax or by investing in solar power

Supporting Information:
- Supporting Information S1

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Impacts of Potential China's Environmental Protection Tax Reforms on Provincial Air Pollution Emissions and Economy

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Abstract China's environmental protection tax (EPT) has been implemented since the beginning of 2018 to control environmental issues (e.g., air pollution). The current EPT law indicates that tax revenues are given to provincial governments without return. However, tax revenue redistribution is the key to achieving a so-called "double dividend"; that is, an environmental tax could benefit both the environment and economic efficiency. Based on our previous analysis of the effectiveness of the current EPT, we further explore whether the double dividend could be achieved under different tax reforms based on the multiregion and multisectoral computable general equilibrium model. We find that recycling the EPT revenue to reduce household income tax (EPT_Int) is an efficient way to achieve the double dividend, and there is no double dividend if the EPT revenue is compensated by reducing enterprise income tax (EPT_Ent) or by investing in solar power (EPT_Sol). Combining EPT_Int and EPT_Sol could be a better approach if more air pollution emissions reductions are required to achieve the national reduction targets. At the provincial level, recycling the EPT revenues to reduce household income tax could offset the negative effect of environmental tax on the economy and achieve the double dividend in all provinces, especially the provinces with higher emission intensity, such as Shanxi, Hebei, Inner Mongolia, and Guizhou Provinces. This result shows that provinces with high emission intensity may further reduce air pollutant emissions during the post-EPT era.

1. Introduction

China's environmental protection tax (EPT) law took effect on 1st January 2018 to control the environmental issues in China. The law subjects enterprises and public institutions that discharge relevant pollutants directly into the environment to taxes for generating air pollution, water pollution, noise, and solid waste. The law also stipulates that tax revenues be collected by provincial governments without any return policy. The introduction of the EPT alone could have a negative effect on the gross domestic product (GDP) in China (Liu & Lu, 2015). However, returning the tax revenues to reduce other distortionary taxes or transferring the revenue to other agents might offset the adverse influence on the GDP and offer additional benefits to both the environment and economy (Andrew & Benoit, 2001). Changing the tax system where there is a shift of the burden of taxes from economic functions to environmentally damaging is called environmental tax reform (ETR). ETR might achieve the "double dividend"—i.e., benefit both the environment and the economy—by two types of effects. In the first dividend (also called the Pigouvian effect), the pollutants are reduced through economic incentives until the marginal external cost is equal to the pollution tax rate. In the second dividend (also called the revenue effect), the revenues collected by the environmental taxes are used to reduce other distortionary taxes so that to improve economic efficiency (Bor & Huang, 2010). Double dividend effect is categorized as "strong" form and "weak" form (Lawrence, 1995). The weak double dividend occurs when welfare increased by using environmental tax revenues to lower distorting taxes is greater than the welfare increased by returning the revenues in a lump-sum fashion. The strong double dividend occurs when welfare is increased in response to an ETR. Thus, the weak double dividend should compare two recycling policies, and the strong form just compare a single policy to the tax revenues without recycling (Bovenberg, 1999).

The first steps in ETR took place in some Nordic countries, such as Sweden, as well as the Netherlands, the United Kingdom, and Germany (Parry et al., 2012). In 1991, Sweden introduced and increased some environmental taxes: a carbon tax, a tax on diesel, a tax on electricity, and taxes on fertilizers, pesticides, aerial traffic, batteries, etc., to reduce some distortive taxes on labor, personal income, and employers' social security contributions (SSCs) (Thomas, 1995). Other countries (such as Germany, Italy, Ireland, and Czech Republic) followed Sweden and successfully implemented tax reform with a common pattern: increasing energy and carbon taxes and decreasing personal or corporate tax income and employers' SSCs (Ekins et al., 2011; Vehmas et al., 1999).

Many studies have explored the types of ETR that achieve the double dividend, including returning tax revenues to reduce the indirect tax on capital and labor or providing lump-sum transfer to households and enterprises. Andrew and Benoit (2001) found that when the revenues are used to reduce other distorting taxes, the economic outcome could be better than if those revenues are not so distributed, in terms of impacts on both employment and GDP in Europe. Ciaschini et al. (2012) concluded that returning the green tax to reduce income taxes allows for the achievement of the double dividend in Italy. However, Klenert and Mattauch (2016) found that when the tax revenue is returned to households via linear income tax cuts, or in proportion to household productivity, the overall effect of the tax reform is regressive. While lump-sum transfers could result in progressive effects. Compared to the reduction of value added taxes and lump-sum transfer, Rodríguez et al. (2019) indicated that the best results are achieved when revenues from green taxes finance are used to reduce SSCs in Portugal. Considering the equity-efficiency trade-off driven by different revenue returning choices, Vandyck and Van Regemorter (2014) found that when revenues are used to raise the welfare transfer to households, the reform is beneficial for lower income groups, but output levels decrease in all regions. Some studies even claimed that the double dividend is not possible because environmental taxes may rise significantly along with economic distortions and thus incur some efficiency losses (Babiker et al., 2003; Goulder, 2013). Freire-González (2018) reviewed 40 previous studies with 69 different simulations of ETRs and found that 55% of simulations have achieved a double dividend. The existing statistical results from the literature showed that although the environmental dividend is almost always achieved, the economic dividend remains uncertain due to the different tax types, returning policies, economic models, and time periods (Oueslati, 2014) used in the simulations.

In China, there has yet been no tax revenue returning policy for the environmental protection tax, and few studies have investigated the impacts of ETR. Bor and Huang (2010) noted that refunding the energy tax revenue to reduce income tax is the best choice with double dividend effects since it effectively stimulates domestic consumption and investment. Liang and Wei (2012) indicated that an ideal solution for the negative impact of carbon tax is to reduce indirect tax with carbon tax revenue while increasing the share of government transfers that rural households obtain. Liu and Lu (2015) found that a production tax deduction can be used to recycle the carbon tax revenue if the government wants to reduce the cost of a carbon tax, while a consumption tax deduction may help restructure economy and may promote long-run emissions reduction. However, these studies are mainly based on the national level or focus one region. Wang, Lin, et al. (2019) conducted a detailed mechanism analysis for provincial EPT collection, but there is no discussion on effects of EPT tax returns. In this study, we intend to evaluate the impacts of EPT returning on provincial air pollution, GDP, and household welfare.

In addition to reducing distortive taxes and lump-sum transfer, earmarking revenues to enhance environmental technology development could strengthen environmental benefits. In Germany, 1% of environmental tax revenues were earmarked for renewable energy deployment. Clinch et al. (2006) found that earmarking a proportion of revenues to environmental projects and returning the rest to reduce labor taxes is probably the best combination in light of their results. Parry et al. (2012) also noted that there could be larger carbon and local air pollution emissions reductions if the upstream taxes on fossil fuels were refunded for downstream emissions capture. As renewable energy development has become increasingly important in mitigating air pollution and climate change, the Chinese government has set goals to increase the power generation from renewable energy technology resources to 20% by 2020. To achieve this target, incentive policies have been set to stimulate renewable energy installation, such as a subsidy for wind and solar power. However, the government subsidy for solar and wind power will end in a few years in China (Shen, 2019). We explore a different policy that returns the EPT revenues for investment in solar photovoltaic (PV) panel installation and consider its impact on air pollution and the economy.

The computable general equilibrium (CGE) model is one of the tools most commonly used to analyze the importance of initial tax distortions and revenue returning options in the analysis of the EPT reforms (Patuelli et al., 2005; Vandyck & Van Regemorter, 2014). In this study, we use the multiregion multisector CGE model to simulate the impact of the ETRs on provincial air pollution, GDP, and household welfare. Previous studies show that returning the environmental tax revenues to reduce distorting taxes could achieve larger welfare than returning the revenues to household and enterprise in lump-sum. This paper only focuses on returning the tax revenues to reduce distorting taxes and invest in solar PV, so the double dividend mentioned in this study is the strong form of double dividend, that is, the tax reform could not only enhance the environmental quality, but also improve the welfare. The tax reforms include returning EPT revenues to (1) reduce household income tax, (2) reduce enterprise income tax, (3) invest in solar PV panel, and (4) reduce household income tax and invest in solar PV panel.

The organization of the remainder of this paper is as follows. Section 2 describes the CGE model and the data we use for the analysis of distributive impacts. Section 3 presents the results and analysis. Section 4 provides conclusions and policy implications.

2. Methods and Data

2.1. CGE Model

We employ a multiregion multisector CGE model for China to investigate multiple aspects of the effects of EPT reform. This CGE model is designed to assess the impacts of energy and climate policies on different provinces and sectors. A detailed algebraic description of the model and the relative parameters are provided in Hu et al. (2019). In this study, we expand the previous CGE model to include different tax revenue returning methods, and here, we present a brief overview of the model. The CGE model is based on the principles of general equilibrium theory which indicate that there exists a steady equilibrium status that the optimal demands equal to optimal supplies of all commodities and factors (Liang & Wei, 2012). Besides, optimizing behavior of economic agents is assumed, that is, firms minimize costs of production and consumers maximize their welfare. Income thus earned is spent on goods, services, and savings. The government collects tax revenues used for consumption, investment, and household transfers. To describe the substitution possibilities between inputs, the nested constant-elasticity-of-substitution cost functions are applied in the module of production, consumption, and trade of goods. In this model, we assume that labor is intersectorally mobile but immobile across regions. Capital is both intersectorally and interregionally mobile.

The dynamic CGE model is driven by labor, capital, and total factor technological progress. Labor growth is exogenous determined by relevant research (Liu, 2014). Capital is accumulated as the previous capital minus depreciation and current investment. Total factor productivity growth rate varies from different sectors, which can be used to "calibrate" the growth path of agriculture, manufacturing, and services.

Energy resources are put into the model as primary factors whose use is associated with the emissions of air pollutants. Emissions from different regions and sectors combine the China Energy Statistical Yearbook 2008 with the PKU-Inventories 2007. Ten pollutants (SO_2, NO_X, TSP, PM_{10}, $PM_{2.5}$, CO, VOC, OC, NH_3, and BC) and CO_2 are included in this model.

The main source of the CGE model is the social accounting matrix (SAM). We have built provincial SAM tables. The SAM table is built on input-output tables, the China Statistical Yearbooks, the China Finance Yearbooks, and the China Taxation Yearbooks. The data sets are aggregated into 30 regions and 12 commodity groups (see Tables S1 and S2 in the supporting information for a description of the regions and sectors used in this study). The elasticities of the model are shown in Tables S3 and S4. The simulation of the baseline has been shown in Hu et al. (2019), and the national GDP, provincial GDP, and industrial structures are all consistent with the national statistics.

2.2. EPT

China's EPT law intends to control environmental issues, including air pollution, water pollution, noise, and solid waste. This study only focuses on the air pollution problem. The EPT for air pollutants are RMB 1.2–12 per pollution equivalent (the current provincial taxes are listed in Table S5). The pollution equivalent value is defined as the air pollution quantity that could reflect the harmfulness of the pollutants and the public cost of dealing with them. It is accounted by the multiplying of air pollutant emissions values (kg) and the

Table 1
The Emission Factors From Coal Power Plants in 2018

	SO_2	NO_X	PM	CO_2
Emission factor (g/kWh)	0.2	0.19	0.04	841

reciprocal of the pollution equivalents (kg/kg). The provincial and sectoral air pollutants emissions values are calculated based on the PKU-Inventory and energy consumption data, which has been applied and validated in our previous study (Hu et al., 2019). And the pollution equivalents for each air pollutant are shown in Table S6.

According to the EPT law, the first three air pollutants ranked in descending order of pollution equivalents, SO_2, NO_X, and CO in this study for all provinces, should be subject to the EPT. The EPT is put into the CGE model as an ad valorem tax on energy consumption (emissions from fossil fuel combustions) and production output (emission from production processing), the formulations are described in Hu et al. (2019).

2.3. Solar Power Investment

To achieve the renewable energy target, China has adopted a series of incentive policies that cover both the national and subnational levels. Solar energy is considered to be one of the cleanest renewable energy sources and has less environmental impact than other renewable energy sources (EU_Final report). As the cost of solar power continues to fall, the subsidies for wind and solar power are being rapidly reduced, and the solar industry might become subsidy-free in a few years (Xinhua, 2019). Using tax revenue to invest in solar PV panel installation is another way to promote clean energy development. The costs of the solar PV panel are shown in Table S7 based on Lv et al. (2019) that the cost breakdown of PV installations is from 5.5 to 5.7 RMB/W. The average cost, 5.6 RMB/W, is used in this study, and the lowest bound and the highest bound of the costs are considered in the sensitivity test. The solar PV generation capacity is 1.2 to 1.5 kWh per Watt per year. Each PV module can be used for 20 to 25 years (Ferrara & Philipp, 2012), and the generation efficiency can be reduced to 85% after 20 years.

Thus, once we know the refund tax revenues, we can obtain the electric generations that could be replaced by the solar PV power. We assume that the substitutions are all from coal power plants. Thus, we can calculate the reductions of emissions after the investment of solar power. The emission intensity for air pollutants and CO_2 are from the Annual Report on the Development of China's Power Industry in 2018 (Wang, Zhang, et al., 2019), as shown in Table 1. Provincial increased power generations of solar PV and the contributions to total power generation are shown in Table 2, the ratio of power generation from new installations are less than 1% in most provinces.

For data limitation, we could only obtain the total power generations in 2018 to simulate the contribution rates from newly installed solar PV. The power generations in 2020 will be larger than that in 2018 (China Industrial Information Network, 2019).

2.4. EPT Reform Scenarios

We compare six EPT reform scenarios against a benchmark case with no EPT policy (see Table 3). In the EPT_Cur scenario, a location-specific EPT from 1.2 to 12 RMB per ton is introduced in different provinces, in line with current legislation. Our previous study shows that current EPT policy has small impact on emissions reductions, and enhancing the tax rate to the highest (12 RMB/kg) could lead to 3–4 times larger emissions reduction in 2018 (Hu et al., 2019). Therefore, in other scenarios, the highest bound of the EPT law with a tax rate of 12 RMB in each province is presented. Under scenarios EPT_Cur and EPT_Gov, there is no tax revenue returning. The tax revenues are retained in the government budget to improve the fiscal position. In the EPT_Int scenario, the EPT revenues are refunded to reduce the household income tax. In the EPT_Ent scenario, the EPT revenues are used to deduct the enterprise income tax. In the EPT_Sol scenario, the EPT revenues are earmarked to install solar PV power. In the EPT_I&S scenario, 50% of the total tax revenue is recycled through the reduction of taxes on household income, and 50% of the revenue is recycled through the investment in solar power.

3. Results

We first present the results for national and regional changes in GDP, air pollution emissions, and household welfare under different tax reform scenarios and then analyze the tax use efficiency.

Table 2
Provincial EPT Revenue, the Increased Power Generations From Solar PV and Their Contributions to Total Power Generation, as well as the CO_2, PM, SO_2, and NO_X Emissions Reduction When the Revenues Associated to the Highest EPT Rates are Used to Invest in Solar PV Installation

	Tax revenue (10 thousand RMB)	Power capacity from solar PV installation (kw)	Power generation (100 million kWh)	Total power generation in 2018 (100 million kWh)	The ratio of generation from the increased solar PV (%)	CO_2 reduction (Gg)	PM reduction (Gg)	SO_2 reduction (Gg)	NO_X reduction (Gg)
Beijing	69,376	123,886	1	450	0.33	125.03	0.01	0.03	0.03
Tianjin	156,066	278,689	3	711	0.47	281.25	0.01	0.07	0.06
Hebei	1,581,228	2,823,621	34	3,133	1.08	2,849.60	0.14	0.68	0.64
Shanxi	1,860,482	3,322,289	40	3,181	1.25	3,352.85	0.16	0.80	0.76
Inner Mongolia	692,974	1,237,454	15	5,003	0.30	1,248.84	0.06	0.30	0.28
Liaoning	782,094	1,396,596	17	1,983	0.85	1,409.44	0.07	0.34	0.32
Jilin	525,130	937,732	11	838	1.34	946.36	0.05	0.23	0.21
Heilongjiang	489,709	874,480	10	1,029	1.02	882.53	0.04	0.21	0.20
Shanghai	211,622	377,897	5	840	0.54	381.37	0.02	0.09	0.09
Jiangsu	1,449,488	2,588,372	31	5,085	0.61	2,612.18	0.12	0.62	0.59
Zhejiang	596,588	1,065,336	13	3,438	0.37	1,075.14	0.05	0.26	0.24
Anhui	900,400	1,607,858	19	2,734	0.71	1,622.65	0.08	0.39	0.37
Fujian	443,574	792,097	10	2,494	0.38	799.38	0.04	0.19	0.18
Jiangxi	333,889	596,231	7	1,281	0.56	601.72	0.03	0.14	0.14
Shandong	1,916,188	3,421,764	41	5,826	0.70	3,453.24	0.16	0.82	0.78
Henan	1,126,598	2,011,783	24	3,050	0.79	2,030.29	0.10	0.48	0.46
Hubei	604,930	1,080,233	13	2,836	0.46	1,090.17	0.05	0.26	0.25
Hunan	1,011,712	1,806,628	22	1,533	1.41	1,823.25	0.09	0.43	0.41
Guangdong	890,245	1,589,723	19	4,695	0.41	1,604.35	0.08	0.38	0.36
Guangxi	282,264	504,043	6	1,752	0.35	508.68	0.02	0.12	0.11
Hainan	28,276	50,493	1	323	0.19	50.96	0.00	0.01	0.01
Chongqing	456,045	814,367	10	800	1.22	821.86	0.04	0.20	0.19
Sichuan	921,894	1,646,239	20	3,687	0.54	1,661.38	0.08	0.40	0.38
Guizhou	471,132	841,307	10	2,016	0.50	849.05	0.04	0.20	0.19
Yunnan	197,761	353,144	4	3,241	0.13	356.39	0.02	0.08	0.08
Shananxi	640,377	1,143,531	14	1,856	0.74	1,154.05	0.05	0.27	0.26
Gansu	271,533	484,880	6	1,531	0.38	489.34	0.02	0.12	0.11
Qinghai	93,919	167,713	2	811	0.25	169.26	0.01	0.04	0.04
Ningxia	185,670	331,553	4	1,610	0.25	334.60	0.02	0.08	0.08
Xinjiang	369,187	659,262	8	3,283	0.24	665.33	0.03	0.16	0.15

Note. The total power generations in 2018 are based on China's National Statistics http://www.stats.gov.cn/.

3.1. National GDP Changes

Figure 1 shows the changes of national GDP under different scenarios comparing to the Baseline. Current EPT law without returning (the EPT_Cur scenario) has a 0.07% negative effect on the national GDP in 2020. Increasing the EPT rates to the highest level (12 RMB/pollution equivalent, the EPT_Gov scenario) in all provinces could result in higher GDP losses of 0.26%. If the tax revenues from EPT_Gov are all used

Table 3
The List of Environmental Protection Tax Reform Scenarios

Scenario	Description
Baseline	No EPT tax
EPT_Cur	Current EPT without returning
EPT_Gov	All provinces apply the highest 12 RMB tax rate without returning
EPT_Int	The tax revenues from EPT_Gov are all used to reduce household income tax
EPT_Ent	The tax revenues from EPT_Gov are all used to reduce enterprise income tax
EPT_Sol	The tax revenues from EPT_Gov are all invested in solar PV installation
EPT_I&S	Half of the tax revenues from EPT_Gov are used to reduce household income tax and half are used to support solar PV installation

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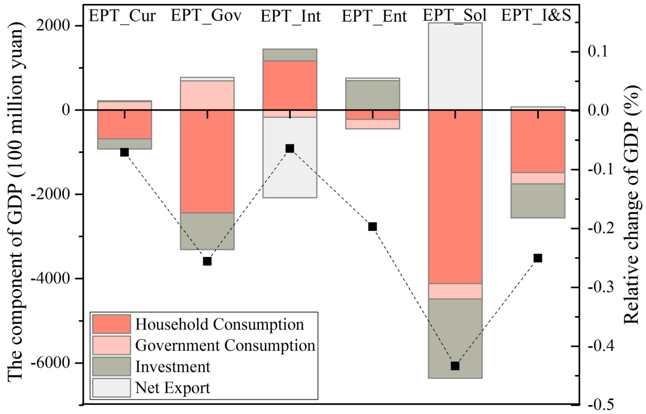

Figure 1. The absolute changes of the different components of GDP (color bars, 100 million RMB) and the relative changes of total GDP (the black dash, %) under different scenarios. The components of GDP include household consumption, government consumption, investment, and net export. Note: the tax rate of the EPT_Cur scenario is based on the current EPT policy, and the tax rates under other scenarios are all based on the highest bound of the EPT law, with 12 RMB per air pollution equivalent being levied over all provinces.

to reduce household income tax (the EPT_Int scenario), the negative effect on GDP (0.06%) is much smaller than that in EPT_Gov and is close to that in EPT_Cur. Using tax revenues to reduce enterprise income tax (the EPT_Ent scenario) results in a 0.2% reduction of GDP. Earmarking all tax revenues from EPT_Gov to invest in solar power installation has the largest negative impact on GDP by −0.43%. Returning half of the tax revenues to reduce the household income tax and half of them to invest in solar power could offset part of the economic damages.

The introduction of the current EPT without cycling (the EPT_Cur scenario) has a negative effect on GDP. This is because the EPT tax could increase domestic prices and reduce household consumption and investment. Since the current EPT revenues are part of local government income, increases in government consumption could offset the GDP loss. For net imports/exports, on the one hand, the increase in domestic prices would decrease domestic demands and reduce imports; on the other hand, the relatively higher domestic prices could stimulate imports with lower prices. The final results depend on these two effects. Under the EPT_Cur scenario, the effects from household demand decrease are larger than the effects from the relatively higher prices; thus, imports are reduced more than exports. While, strengthening the tax rate with a 12 RMB tax rate (the EPT_Gov scenario) could have a larger negative impact on the GDP value with a similar variation path.

Returning the EPT revenue to reduce household income tax (the EPT_Int scenario) could offset the negative effect on the economy from the environmental tax. Reducing household income tax leads to increases in household disposable income, which in turn encourages consumption and investment. The increases in household demand stimulate imports, which result in a decrease in net exports. The economic growth thus created is more significant and leads to greater double dividend effects.

Returning the EPT revenue to reduce enterprise income tax (the EPT_Ent scenario) can effectively lower production costs for the industries concerned as well as encourage investment, which in turn prompts the producers to improve efficiency and expand their production facilities. However, the household consumption still decreases. The decrease in household demand could notably reduce imports and result in small increases in net exports.

When all the revenues from the EPT are allocated to invest in solar power (the EPT_Sol scenario), the subsequent increase in consumption and investment is far less than the reduction of household income tax and enterprise income tax. The solar PV installation could stimulate the development of other interdependent economic sectors and increase GDP, but the impacts are so small that we can ignore, the details are shown in Table S8. Besides, the introduction of EPT could reduce the productions in air pollution-intensive sectors (shown in Table S9) and result in exports decrease from these sectors. While the productions in rest of the sectors will increase, which stimulate the exports. In total, the export change is positive, and the import change is negative (see Table S10). Thus, the net export would increase under the EPT_Sol scenario. As a result, scenario EPT_Sol has a greater negative impact on economic development.

The impacts of economic growth under scenario EPT_I&S are between the EPT_Int scenario and the EPT_Sol scenario because half of the tax revenue is used to invest in solar power, and consequently, less income tax is reduced.

3.2. National Emissions Change

Levying EPT could reduce the air pollutants and benefit CO_2 mitigation. However, the reduction rates under the current EPT policy are all predicted to be less than 1% in 2020 (see Figure 2). Enhancing the tax rate with the highest revenues leads to 3–4 times larger emissions reduction than the current EPT policy. Returning the highest tax revenues to reduce the household income tax (the EPT_Int scenario) leads to slightly more emissions reductions compared to the highest revenues without returning (the EPT_Gov scenario). However, returning the highest tax revenues to reduce the enterprise income

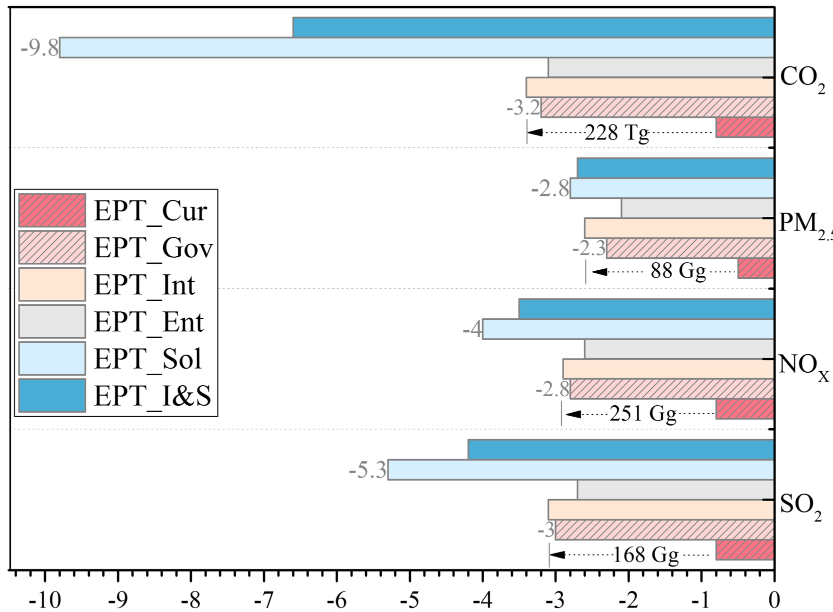

Figure 2. The relative changes in SO_2, NO_X, $PM_{2.5}$, and CO_2 emissions under EPT_Cur (current EPT policy), EPT_Gov (the highest bound of the EPT law without return), EPT_Int (revenues from EPT_Gov used to reduce household income tax), EPT_Ent (revenues from EPT_Gov used to reduce enterprise income tax), EPT_Sol (revenues from EPT_Gov used to invest in solar power), and EPT_I&S scenarios (half of the revenues used to reduce household income tax and half used to invest in solar power) compared to the baseline (i.e., no EPT tax).

tax (the EPT_Ent scenario) entails relatively lower emissions reductions than EPT_Gov. Earmarking all the revenues to invest in solar power (the EPT_Sol scenario) has the largest emissions reductions. In addition, earmarking half of the revenues from EPT_Gov to invest solar power and half of them to reduce the household income tax could lead to more than half the reductions of emissions in the EPT_Sol scenario.

The increases in production prices in air pollutant-related sectors caused by the EPT could decrease the fossil fuel energy demand and air pollution-relevant industrial processes and result in emissions reduction. The reduction rate of CO_2 emissions is larger than the reductions in air pollutants because the sectors that are highly affected by the EPT have a larger contribution to CO_2 emissions than the air pollutants, such as the electricity power sector. Strengthening the tax rate with the 12 RMB per pollution equivalent (the EPT_Gov scenario) has 3–4 times larger emissions reductions than the current EPT policy, with 3%, 2.8%, 2.3%, and 3.2% reductions of SO_2, NO_X, $PM_{2.5}$, and CO_2, respectively.

Returning the highest tax revenues to reduce household income tax (the EPT_Int scenario) has relatively slightly higher emissions reductions compared to the EPT_Gov scenario. The EPT_Int scenario could stimulate household consumption caused by increasing disposable income, and increase the productions in most sectors (see Table S9). However, comparing to EPT_Gov, the EPT_Int scenario has larger increases in household consumer goods productions, such as agriculture sector, light industries, and services sector, but has less increases in productions of air pollution-intensive goods. The emission factors regarding to the household consumer goods are relative smaller. Thus, the air pollutants emissions reductions are relatively larger in EPT_Int than EPT_Gov.

However, returning the highest tax revenues to reduce enterprise income tax (the EPT_Ent scenario) has relatively lower emissions reductions than the EPT_Gov scenario. The lower production costs caused by the enterprise income tax reductions could stimulate production in some sectors, such as the metal manufacturing sector (shown in Table S9), which would increase the demand for energy and result in relatively more emissions than would result from the EPT_Gov scenario.

Earmarking all the revenues to invest in solar power (the EPT_Sol scenario) has the largest reductions of emissions, with 5.3%, 4%, 2.8%, and 9.8% reductions of SO_2, NO_X, $PM_{2.5}$, and CO_2, respectively. The

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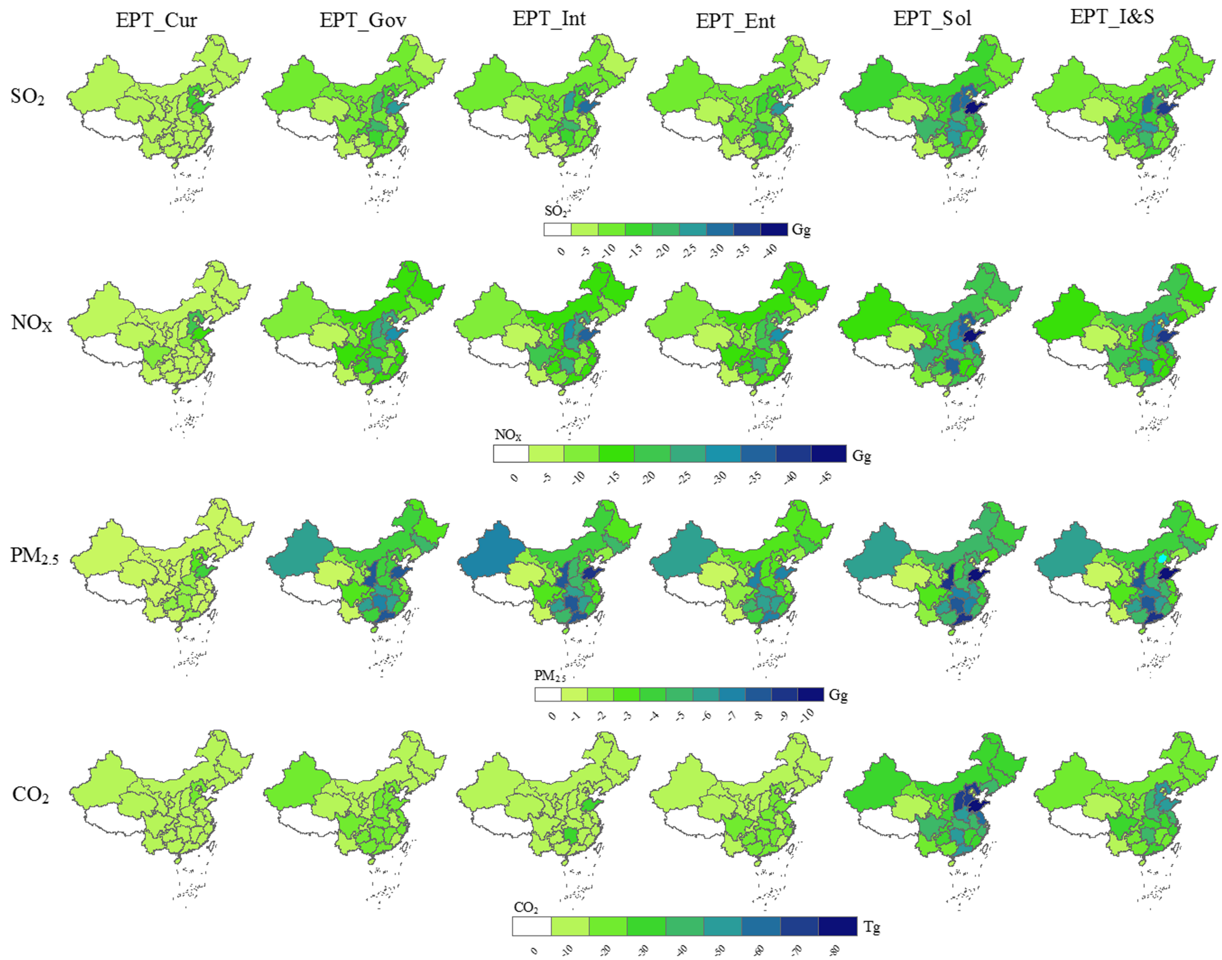

Figure 3. Provincial changes in SO_2 (the upper row, Gg), NO_X (the second row, Gg), $PM_{2.5}$ (the third row, Gg), and CO_2 (the bottom row, Tg) under different scenarios (i.e., EPT_Cur: current policy; EPT_Gov: the highest rates of EPT without returning; EPT_Int: the highest rates of EPT with all tax revenues used to reduce household income tax; EPT_Ent: the highest rates of EPT with all tax revenues used to reduce enterprise income tax; EPT_Sol: the highest rates of EPT with all tax revenues used to invest in solar power; EPT_I&S: the highest rates of EPT with half of the tax revenues used to invest solar power installation and half of the revenues used to reduce household income tax) compared to the baseline in 2020.

reduction rates of CO_2 and SO_2 emissions are relatively larger because the electricity power sector has larger emissions factors for these two pollutants, as shown in Table 1. Additionally, earmarking half of the revenues to invest in solar power and half of them to reduce income tax could lead to more than half the reductions observed in the EPT_Sol scenario.

In summary, combining the effects of both national GDP and air pollutant emissions, we find that enhancing the EPT to the highest rates and returning EPT revenues to reduce the household income tax (the EPT_Int scenario) is the best among the six scenarios proposed in this study because it causes relatively smaller GDP losses but more reductions in air pollutant emissions compared to all other scenarios. However, earmarking half of the revenues to invest in solar power and half of them to reduce the household income tax (the EPT_I&S scenario) is another good option because it has a level of GDP loss similar to that in the EPT_Gov scenario but generates much more emissions reductions.

Our estimates of the impact of ETR in China are nearly similar to the findings in previous studies. For example, Bor and Huang (2010) used a dynamic CGE model to analyze the economic impacts of energy tax in Taiwan and found that reducing household income tax has the greatest double dividend effect compared to reducing enterprise income tax and reducing both household and enterprise income tax. Although the results presented here hold just for a specific set of parameters, the sensitivity analysis, provided in the supporting information, indicates the conclusions are robust.

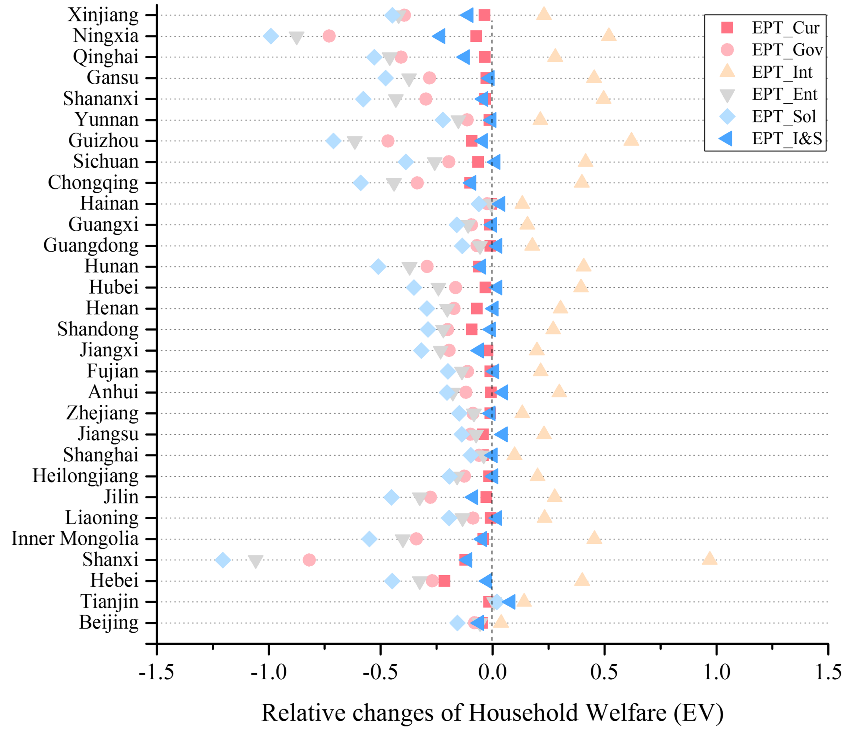

Figure 4. Spatial changes in household welfare under different scenarios compared to the Baseline in 2020. Colors indicate different scenarios, including EPT_Cur (current policy), EPT_Gov (the highest rates of EPT without returning), EPT_Int (the highest rates of EPT with all tax revenues used to reduce household income tax), EPT_Ent (the highest rates of EPT with all tax revenues used to reduce enterprise income tax), EPT_Sol (the highest rates of EPT with all tax revenues used to invest in solar power), and EPT_I&S (the highest rates of EPT with half of the tax revenues used to invest solar power installation and half of the revenues used to reduce household income tax).

3.3. Provincial Air Pollution and Household Welfare Changes

The spatial changes of SO_2, NO_X, $PM_{2.5}$, and CO_2 emissions among different returning scenarios are generally consistent with the national changes (see Figure 3). For different air pollutants, the spatial changes of SO_2 and NO_X are similar under different scenarios, with the largest reductions occurring in Shandong, Shanxi, and Hebei Provinces. Compared to SO_2 and NO_X, substantial reductions in $PM_{2.5}$ emissions also occurred in Shaanxi, Xinjiang, and Guangxi Provinces because of the high $PM_{2.5}$ emission intensity in these regions. For CO_2 emissions, earmarking all revenues to invest in solar power has obvious impacts on Shandong, Shanxi, Hebei, and Jiangsu Provinces. Because the basic emissions from the electricity power sector are high in these provinces, the investment in solar power could largely reduce CO_2 emissions.

Besides, we use a comprehensive and unified index, air pollution equivalent, to measure the changes in provincial air pollution under different scenarios. The results are shown in Figure S1. The provincial air pollution equivalents are calculated based on main air pollutant emissions, including SO_2, NO_X, CO, and PM. Consistent with the spatial changes in SO_2, NO_X, and $PM_{2.5}$, the air pollution equivalent values decrease over all regions under all EPT reform scenarios compared to the baseline in 2020. The largest air pollution reductions occur in provinces with large economic scale, such as Shandong province, and in provinces with high air pollution emission intensity, such as Shanxi and Hebei Provinces.

To capture welfare changes, we employ the equivalent variation indicator that, at base prices, measures the changes in income needed to avert the simulated induced changes (Hanslow, 2000). The EPT without returning (including EPT_Cur and EPT_Gov scenarios) would damage household welfare in all regions, especially in the regions that suffer a relatively larger burden from the EPT due to their higher emission intensity, such as Shanxi, Inner Mongolia, Hebei, Chongqing, Guizhou, and Ningxia Provinces (see Figure 4).

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However, all provinces could achieve the double dividend under the EPT_Int scenario. This is because returning revenues to reduce household income tax would increase disposable income, which would stimulate household consumption and improve human welfare. Shanxi, Inner Mongolia, Hebei, Guizhou, and Ningxia Provinces receive relatively greater household welfare because the extent of the reduction of household income tax is larger in these provinces, as shown in Figure S2.

Similar to the EPT_Int scenario, the combination of reducing household income tax and investing in solar power could also achieve the double dividend in some regions, such as Jiangsu, Tianjin, Anhui, and Guangdong Provinces. However, when the EPT is compensated to reduce enterprise income tax or solely invest in solar power, there is no double dividend in all provinces.

By comparing the effects of different EPT reforms, it is obvious that strengthening the current EPT and returning tax revenues to reduce household income tax is the most efficient way to reduce air pollution from high emission intensity regions. To reduce more air pollutant emissions, returning half of the tax revenues to invest in solar power is the second-best option, which substantially reduces both CO_2 and air pollution emissions with almost no impact on household welfare.

4. Conclusion and Policy Implications

Based on the analysis of the provincial and sectoral impacts of the EPT law and the potential emissions reduction, this paper further studies the effects of different EPT tax reforms on GDP, air pollution, and household welfare in different provinces in China based on the CGE model. The results show that current EPT law has the lowest GDP loss (by −0.07%) but the smallest emissions reductions (less than 1%). Enhancing the EPT to the highest tax rate (12 RMB/pollution equivalent) in all regions (the EPT_Gov scenario) could result in an increase in GDP loss by a factor of 3 (−0.26%) and 3–4 times more emissions reductions compared to the current policy. Returning the EPT revenues from EPT_Gov (the highest tax rate) to reduce the household income tax (the EPT_Int scenario) has much lower GDP losses and relatively higher emissions reductions than the EPT_Gov scenario. While, returning the highest tax revenues to reduce enterprise income tax (the EPT_Ent scenario) has smaller damage to GDP but also relatively lower emissions reductions compared to the EPT_Gov scenario. Earmarking all revenues to invest in solar power (the EPT_Sol scenario) has the largest emissions decline but the largest GDP loss. Earmarking half of the revenues to invest in solar power and half to reduce the household income tax (the EPT_I&S scenario) has a GDP change similar to that in the EPT_Gov scenario but results much more reductions in CO_2 and other short-lived air pollutant emissions.

Thus, at the national level, if reducing more emissions while keeping GDP at the current EPT level is the target, the best choice is to raise the EPT tax rate to 12 RMB per pollution equivalent in all regions and then recycle the EPT revenues to reduce household income tax. To achieve a much more ambitious emissions reduction target, it is also possible to earmark half of the tax revenues to reduce household income tax and half of the revenues to invest in solar power, which will generally keep the household welfares unchanged.

At the regional level, increasing EPT tax rates to the highest level while returning all tax revenues to reduce household income tax is again the most cost-effective way to reduce air pollution and CO_2 emissions. Such a policy could achieve the double dividend in all provinces, especially in those with relatively higher emission intensity, such as Shanxi, Inner Mongolia, Hebei, Guizhou, and Ningxia Provinces. This result could promote the provinces with high emission intensity to reduce more air pollutants and CO_2 emissions.

This study intended to evaluate the effectiveness of different reforms of the EPT policy based on our previous study, but there are still some uncertainties in the CGE model, costs of solar PV installation, and emissions inventories. The uncertainties in the CGE model have been discussed in the last paper (Hu et al., 2019), and the results show that the elasticity of substitution between capital and energy is the most sensitive parameter in the model. For the uncertainties from costs of solar PV installation and emissions inventories, we collect the minimum and maximum values based on previous studies and other widely used data sources. We then conduct sensitivity tests with the combination of these major uncertainties. The results in Figures S3 and S4 show that although uncertainties exist in this study, the main conclusion is robust. We will address these issues step by step as more data and measurements become available in our follow-up studies.

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The detailed CGE model description and relative parameters are available for previous paper in Hu et al. (2019). The cost breakdown of PV installations data are available in Lv et al. (2019). Emissions inventory are from PKU-Inventory (http://inventory.pku.edu.cn/). All the data used in this analysis are openly available as indicated in the data sources and in the supporting information. This work was supported by funding from the National Natural Science Foundation of China under award 41671491 and 41821005, the Newton Advanced Fellowship (NAFR2180103) and the National Key Research and Development Program of China 2016YFC0206202.

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