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a general equilibrium analysis

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Distributional impacts of taxing carbon in China: a general equilibrium analysis

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Abstract

This study aims to examine how mitigating CO_2 through a carbon tax might affect the development goals of narrowing urban-rural gap and improving people's living standard. In this study, the China Energy & Environmental Policy Analysis (CEEPA) model, a recursive dynamic computable general equilibrium model, was employed to simulate taxing carbon in China. Different carbon tax schemes were designed and their impacts on household disposable income, household welfare, economic growth, and CO_2 emissions were compared. Results show that, given the current social security system that obviously favors urban households and the current investment-driven economic growth pattern, without complementary measures for protecting households, a carbon tax will not only widen the urban-rural gap, but also reduce the living standards of both urban and rural households. The negative impacts caused by carbon tax will enlarge over time. An ideal solution, no matter under an emission intensity goal or a total amount control goal, is to reduce indirect tax with carbon tax revenue, whilst increase the share rural households obtain in government transfers.

Keywords: carbon tax, computable general equilibrium, income distribution

1. Introduction

China has unveiled its target for limiting greenhouse gas emissions. Any mitigation activity will accompany cost. However, economic development, poverty reduction, and improvement of the people's living standards and quality, are still main priorities of China. For example, the government [1] has set the following objectives: "On the basis of optimized structure and better economic returns, efforts will be made to quadruple the GDP of 2000 by 2020" and "achieve industrialization by 2020." Therefore, when selecting and designing mitigation measures, the nation's basic socio-economic development targets should be taken into account as much as possible.

Carbon tax has been long receiving much attention [2-4]. It is one of the most possible carbon mitigation alternatives in China especially in the near future. In fact, National Development and Reform Commission (NDRC) and the Ministry of Finance (MOF) had issued their joint special report, proposing that a carbon tax should be levied in China by the year 2012 [5]. Therefore, it is not only necessary but also urgent to perform researches on carbon tax policy in China.

Countries with the longest history of taxing carbon include Finland, Sweden, Norway, Netherlands and Denmark. All these five countries introduced carbon tax in early 1990s. The tax schemes of these countries are obviously different in the setting of primary elements such as tax rate, manner of tax relief, manner of revenue recycling, and are modified frequently after first levies [6, 7]. Therefore, designing a carbon tax policy would be a complicated process. The specific economic situation of each single country should be taken into account when designing an environmental policy such as carbon tax [8] and there are important differences between countries in price responses [9]. Though there is no uniform experience to follow yet, the international practice of carbon tax, however, do show that besides macro-economic impacts,

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two other important concerns about carbon tax are its impacts on competitiveness and on income distribution, which should be carefully addressed in the design of a tax scheme [6, 7, 10, 11]. We have already carried out studies focusing on the potential impacts of carbon tax on the macro economic growth and on energy- and trade-intensive sectors in China [12]. Here the focus is put on the income distribution effect.

There exist a number of studies about the income distribution effect of carbon tax, most of which are focused on developed countries. Speck [13] and Callan et al. [14] respectively has performed an early and recent review of existing studies: in general a carbon tax is regressive in developed countries, but with different extent in different countries; through properly setting the elements of a tax scheme such as tax revenue recycling [14], object of taxation [15], the regressive effect of carbon tax could be alleviated or even removed.

Due to the obvious divergences in household income and consumption pattern, existing research results about developed countries are not readily applied to developing countries [16]. However, up to now, studies about the impacts of taxing carbon in China on income distribution are mostly qualitative. Results from the few quantitative analyses are not unanimous: Brenner et al. [16] found that introducing carbon charges in China would have a progressive impact on income distribution, which would be further enhanced by recycling carbon revenues on an equal per capita basis. Wang [17] found that carbon tax helped to narrow the urban-rural income gap, but inside both urban and rural, carbon tax showed strong regression, which will surpass the reduction of urban-rural income gap thereby will increase the national Gini coefficient. Therefore, related researches about China need to be strengthened, especially given the current severe status of income distribution in China.

The extent to which general equilibrium effects are taken into account is one of the major factors affecting the size and direction of the aggregate impact of carbon tax on income distribution [18]. However, considerations about this factor in current related quantitative studies about China are still relatively limited. These studies usually focused on the direct effect of carbon tax on household expenditures, with assumptions of fixed per capita expenditures and fixed ratio of embodied carbon for all commodities. However, given the fundamental role of the initial objects of taxation, the effects of a carbon tax will eventually ripple throughout the economy and the outcomes could be surprising [18]. Current related studies about China are not able to grasp feedbacks from the rest of the economic system, e.g. how the effects of carbon tax will impact household factor income thereby influence household expenditure and welfare? Therefore, this study contributes to existing researches through assessing the income distribution impacts of a carbon tax on households in China under a general equilibrium framework. Moreover, with a dynamic analysis framework, this study can estimate how the effects of carbon tax on economic growth will impact households over time, which is also seldom discussed in existing relevant studies about China. Furthermore, discussions about carbon tax revenue recycling in current studies about China are relatively simple. This study contributes in this aspect by simulating more alternatives for revenue recycling thereby examines how to properly introduce complementary policies to alleviate negative effects or strengthen positive effects.

The rest of the paper is organized as follows. Section 2 introduces the model used in this study. The setting of carbon tax schemes is illustrated in Section 3; major results and discussions are presented in Section 4. This is followed by corresponding conclusions and policy recommendations in Section 5. Finally, further work required to improve the current study is presented in Section 6.

2. Methodology

2.1 Model framework

This study is based on the China Energy & Environmental Policy Analysis (CEEPA) model, which is a multi-sector recursive dynamic computable general equilibrium (CGE) model developed by Center for Energy and Environmental Policy Research, Beijing Institute of Technology. The CGE model stems from the general equilibrium theory of Walras [19]. It uses a set of simultaneous equations to describe the behaviors of different agents and their interactions in macroeconomic systems. CEEPA follows the basic notion of a general CGE model and assumes that two types of agents are included in the economic system, i.e. producers and consumers; according to the principle of revenue maximization, producers decide the optimal volume of supply under the restriction of resources and technology; according to the principle of utility maximization, consumers decide the optimal volume of demand under the restriction of budget; price is the only signal in the system guiding the behaviors of each agent, and there exists a set of equilibrium prices, which equal the optimal supplies and optimal demands of all the commodities and factors, thus the whole economy reaches a steady equilibrium status. The framework of CEEPA is illustrated in Fig.1. In CEEPA, consumers are divided into households, enterprise and government to reflect their different roles in policy disturbances. Different types of consumers are interacting through taxes, transfer payments, etc. Moreover, considering the current energy- and emission-intensive international trade structure of China, a foreign account was included, making CEEPA an open model. CEEPA is composed of five basic sub-modules, i.e. production, income, expenditure, investment and foreign trade sub-module. Detail introductions about CEEPA and related lists of equations, parameters and variables please refer to Liang et al. [12, 20].

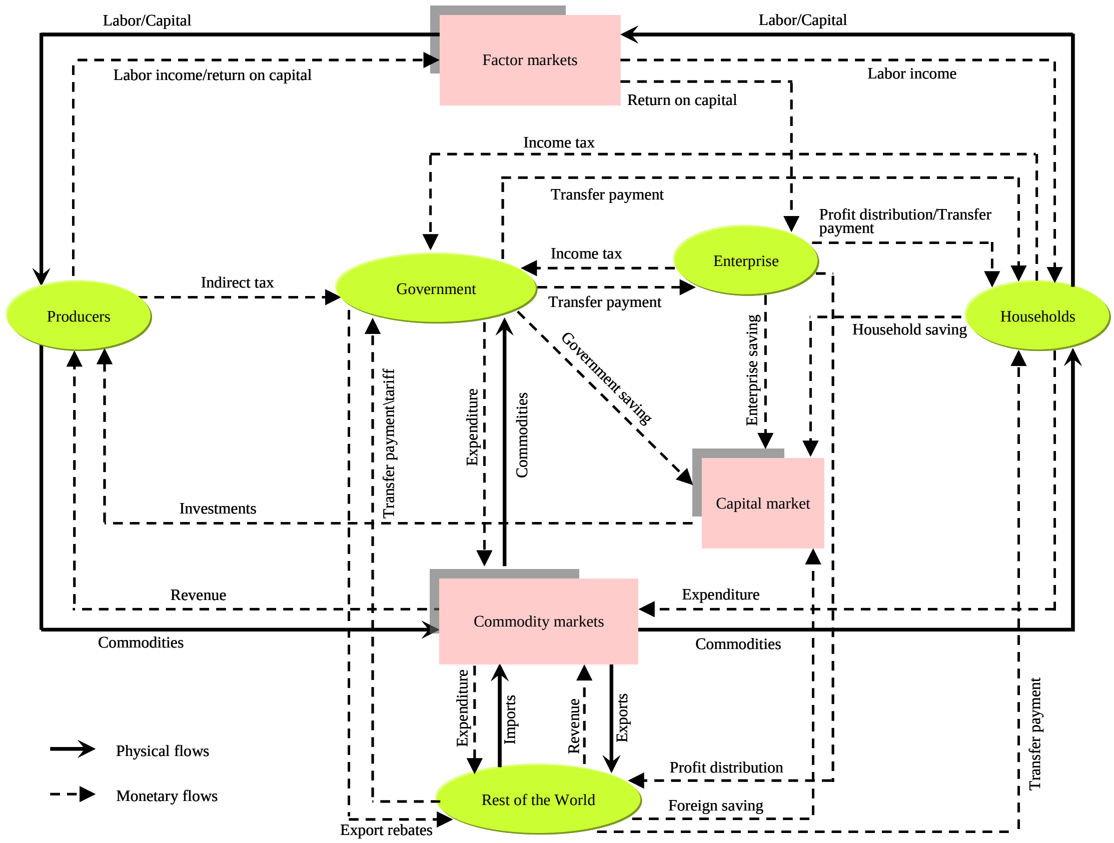

Fig. 1. Framework of CEEPA

2.2 Data source

The core database of a CGE model is the Social Accounting Matrix (SAM), which describes in detail the economy in a country or a region in a given period (usually a year). In this study we updated the SAM2002 used in our previous studies and calculated the China SAM 2007 based on the China input-output table 2007 [21] and miscellaneous yearbooks and literatures [22-27].

Besides SAM, this model requires exogenous and endogenous parameters. The endogenous parameters are decided using the method of calibration. Exogenous parameters in this model include miscellaneous substitute elasticities, carbon emission factors, the composition matrix of fixed capita, total factor productivity, etc. This part of parameters is obtained from related research [28-32], and with our own adjustments.

3. Carbon tax schemes

Six carbon tax schemes are analyzed in this study, as shown in Table 1.

For each scheme, the object of taxation is assumed to be coal, crude oil and natural gas; the tax base is assumed to be the carbon-content of fossil fuels; the tax is assumed to be levied from year 2012, following the proposition in the NDRC-MOF joint special report; tax rate also follows the recommendation in the NDRC-MOF joint special report, and is assumed to be 10 Yuan/ton CO_2.

The difference among schemes lies in their different manners of levy, or different manners of revenue recycling:

Scheme NN is the "no-protection scheme", in which there is no any tax incentives and all the tax revenue is assigned to government income;

Two types of methods could be used to alleviate the negative impacts of taxing carbon on income distribution [13]: one is ex ante, referring to reduce or exempt the tax burden of some vulnerable groups; another is ex post, referring to compensate or offset the negative effects on particular groups. NDRC and MOF proposed the ex ante method in their joint report, i.e. exempting households from carbon tax. Scheme EH is set to simulate this method. Ex post methods mainly include a 'lump-sum redistribution' of fiscal revenues to population, reduction in 'labor taxes' or in 'income taxation', or 'changes in social security system' [10,13]. Scheme LS and RI respectively simulates scenarios where carbon tax revenue are used for a lump-sum redistribution and a reduction in household income tax. Since there is no labor tax in China, in this study the impacts of lowering labor tax is approximately simulated by lowering indirect tax, corresponding to scheme IT. Moreover, lacking of necessary data, the current model is not able to describe the social security system in detail, thus here it is approximately represented by government transfers to households, corresponding to scheme GH.

Table 1 Description of carbon tax schemes

Scheme	Description
NN (**N**o**N** protection)	No tax incentives and no tax revenue recycling
EH (**E**xempting **H**ouseholds)	Households are exempted from carbon tax
LS (**L**ump-**S**um transfer)	All the carbon tax revenue is redistributed to households as a lump-sum transfer, which is distributed between rural and urban in proportion to the population
GH (**G**overnment to **H**ouseholds)	All the carbon tax revenue is used to increase government transfers to households, according to the current transfer ratios

RI (**R**educing **I**ncome tax)	All the carbon tax revenue is used to reduce household income tax by a uniform rate
IT (reducing **I**ndirect **T**ax)	All the carbon tax revenue is used to reduce indirect tax by a uniform rate

4. Results analysis and discussions

A baseline scenario encompassing up to 2020, the year China aims to realize its greenhouse gas control target, was run where no emission restriction and no carbon tax existed. Then the model was rerun to simulate the six carbon tax schemes. The following illustrates the major results expressed in variations from the corresponding baseline values.

4.1 Impacts of different carbon tax schemes on household disposable income

Fig.2 shows the impacts of different carbon schemes on household disposable income.

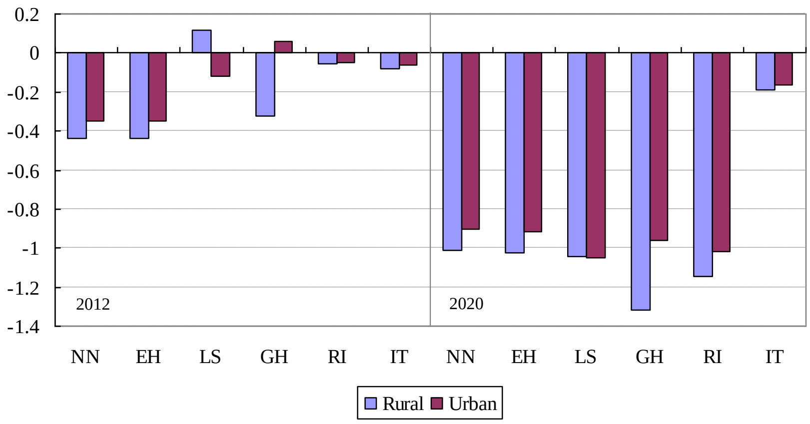

Fig. 2. Variations of household disposable income under different carbon tax schemes (%)

Household disposable income is composed of factor and transfer income. Impacts of any given carbon tax scheme on disposable income are decided by the integrate impacts of its manner of levy and manner of revenue recycling on factor and transfer income. As for factor income, a carbon tax directly raises the cost of energy input in each sector, thus decreases sectoral output and leads to the reduction in factor income. Factor income could be increased through using the carbon tax revenue to reduce existing distortionary taxes. As for transfer income, the impacts of taxing carbon on existing transfer incomes are weak. Transfer income could be increased through reimbursing the carbon tax revenue for transfer payments.

The integrated impacts of different carbon tax schemes are as follows:

(1) Without protections for households (scheme NN), the urban-rural income gap will be expanded, and both the income of urban and rural households will decrease: under this scheme, carbon tax revenue has no direct contribution to either factor or transfer income. The weak impacts of taxing carbon on existing transfer income, on the one hand make household disposable income vary in the same direction as factor income, i.e. both being negative, on the other hand cushion in a sense the decrease in total income. Given that currently the share of existing transfer income in total income of urban households is much greater than that of rural households, the decrease in urban households' disposable income is smaller than rural households;

(2) Exempting households from carbon tax (scheme EH) has weak effect on either preventing the expansion of urban-rural income gap, or reducing the negative impacts on household income: here carbon tax is assumed to be levied as a consumer tax, thus exempting households has no direct effect on the income side.

(3) If all the carbon tax revenue is transferred to households in proportion to the population (scheme LS), the urban-rural income gap can be narrowed compared to before the tax is imposed, but in the long term greater negative impacts will be incurred on both urban and rural income level than the no-protection scheme: compared to scheme NN, the increase in transfer income can obviously reduce the negative impacts on household income, with rural households obtaining more from this way of revenue transfer.

(4) If the transfer of carbon tax revenue follows the current pattern of government transfers to households (scheme GH), the urban-rural income gap will be further expanded compared to the no-protection scheme: this is because currently in China the government transfers to households are mainly enjoyed by urban households

(5) If carbon tax revenue is used to reduce household income tax by a uniform rate (scheme RI), in the long term the urban-rural income gap will also be further expanded compared to the no-protection scheme: currently in China the income tax rate of urban households is greater than that of rural households, hence when the income tax rate is reduced with a uniform rate the negative impacts on factor income of urban households could be alleviated to a greater extent.

(6) If carbon tax revenue is used to reduce indirect tax (scheme IT), the urban-rural income gap will be expanded with an extent obvious smaller than the no-protection scheme, and in the long term this scheme performs much better in protecting household income level than the other schemes: this scheme directly reduces the increase in production cost caused by carbon tax, thus reduce the negative impacts on factor income through protecting production.

4.2 Impacts of different carbon tax schemes on household welfare

Fig.3 shows the impacts of different carbon tax schemes on household welfare. Welfare reflects the contented state that households achieve through the consumption of various goods and services. It can measure the impacts of carbon tax on household life from the perspective of expenditure. Here welfare is described with the percentage of Hicksian equivalent variation over the base year household consumption.

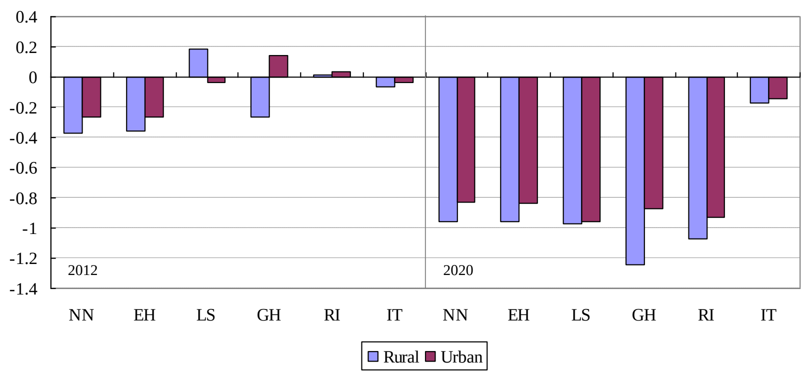

Fig. 3. Variations of household welfare under different carbon tax schemes (%)

Results show that, the ranking of the impacts of different schemes on household welfare is generally consistent with the ranking of their impacts on household disposable income. The main difference is, from the perspective of expenditure, it is hard for scheme LS to maintain its advantage in narrowing urban-rural gap in the long term. This is mainly because that: household expenditure is co-decided by household income level and the price level of commodities, and is positively correlated with the former while negatively correlated with the latter; with a higher share of coal in its consumption structure, in the whole period analyzed rural households face a higher price level of commodities than urban households; in the initial period of taxing carbon, rural households obtain much more share of carbon tax revenue transfer than urban households, which surpass their disadvantage in higher price level, thus they obtain more protection in expenditure than urban households; in China there is an obvious increasing trend of urbanization over time, which will decrease the share rural households obtain from carbon tax revenue transfer; the lower carbon tax revenue transfer income, coupled with the higher price level, will in the long term lead to greater welfare loss of rural households than urban households.

4.3 Impacts of different carbon tax schemes on economic growth

The long term impacts of different carbon tax schemes on household disposable income and welfare are decided by their impacts on economic growth.

Fig.4 shows the variations of GDP under different carbon tax schemes. The impacts on GDP are negative and increasing over time under all the schemes. In the long term, GDP loss under scheme LS, GH and RI, where carbon tax revenue is directly reimbursed to households, is much greater than the other schemes. In the whole period analyzed, GDP loss under scheme IT is much smaller than the other schemes. Moreover, the increasing of GDP loss over time is also the slowest under scheme IT.

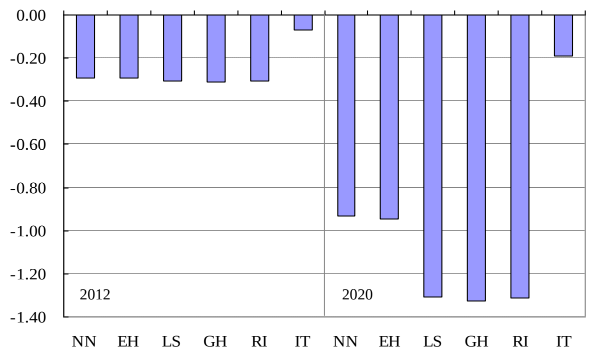

Fig. 4. Variations of GDP under different carbon tax schemes (%)

Given the current investment-driven economic growth pattern, the differences in the impacts of different schemes on economic growth mainly stem from the differences of their impacts on investment. In this model total investment is completely endogenously transformed from total saving. Therefore, the differences in the impacts of different schemes on economy and household life are decided by the differences in their impacts on various savings, as shown in Fig.5:

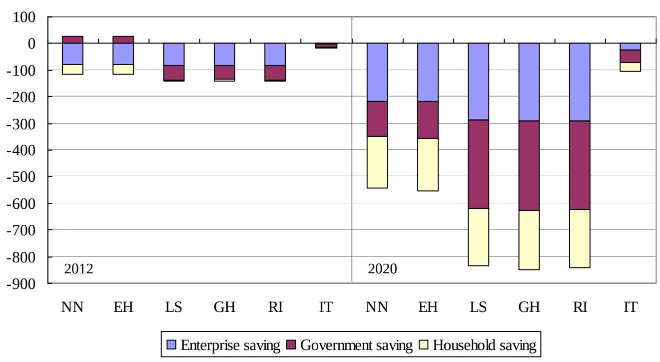

Fig. 5. Impacts of different carbon tax schemes on various savings (billion Yuan)

The negative impacts of carbon tax on total saving increase over time under all the schemes.

If carbon tax revenue is directly reimbursed to households, either in the way of transfer payment or of income tax reduction, the negative impacts on total saving will be greater than the no-protection scheme. As show in Fig.5, the negative impacts on household saving under these schemes can be obviously reduced in the initial period of taxing carbon. However, as shown in Fig.6, the decrease in indirect tax revenue can not be compensated by carbon tax revenue under scheme LS and GH, and the incorporation of carbon tax revenue is not enough to compensate the decrease in indirect tax revenue and household income tax revenue under scheme RI. Therefore, carbon tax will have obvious negative impacts on government saving under these three schemes. Such negative impacts will surpass the extent the negative impacts on household saving are improved, thus lead to greater negative impacts on total saving thereby greater negative impacts on households under these three schemes.

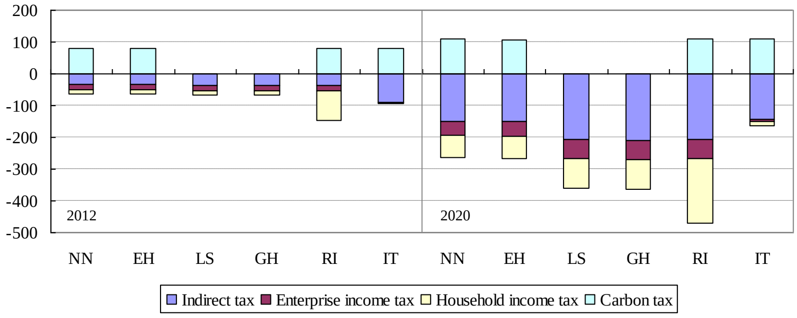

Fig. 6. Impacts of different carbon tax schemes on various taxes (billion Yuan)

If all the carbon tax revenue is used to reduce indirect tax, the negative impacts on total saving will be much smaller than the other schemes. A decrease in indirect tax rate obviously cushions the negative impacts on production activity under this scheme, thus the negative impacts on factor income thereby the negative impacts on enterprise and household saving, are obviously reduced. As for government saving, on the one hand, the decrease in income tax revenue under this scheme is much smaller than other schemes; on the other hand, in the initial period of taxing carbon the reduction in indirect tax revenue caused by decrease of indirect tax rate can mostly be compensated by carbon tax revenue, in the long term, since production is more protected, the decrease in indirect tax revenue is smaller under this scheme than other schemes even if the indirect tax rate is lowered. In the whole period analyzed the negative impacts on government saving under this scheme is also the smallest among all the schemes where government saving is negatively impacted.

4.4 Impacts of different carbon tax schemes on CO_2 emissions

Table 2 shows the impacts of different carbon tax schemes on CO_2 emissions. Results show that, the effects of different schemes on reducing emission intensities are close to each other, with the largest decreasing amplitudes being only 0.1 percentage point greater than the smallest one; while their effects on reducing accumulated CO_2 emissions are obviously different from each other, with the largest reduction realized (scheme GH) being 20% greater than the smallest one (scheme IT). Therefore, if a total amount control goal is adopted, carbon tax rates under different schemes should be adjusted accordingly. This brings a new question here: will the change of applicable tax rates affect the ranking of different schemes in their impacts on economy and household living? For this question, here a sensitivity analysis was performed: supposing that for each scheme accumulated CO_2 reduction from year 2012-2020 should reach 5%. Results show that, the ranking of the impacts of different schemes on household income, household welfare and economic growth is consistent with that in the uniform tax rate case.

Table 2 Impacts of different carbon schemes on CO_2 emissions (%)

	NN	**EH**	**LS**	**GH**	**RI**	**IT**
Accumulated CO_2 reduction from year 2012-2020	-3.19	-3.14	-3.42	-3.43	-3.42	-2.53

Carbon intensity 2020 VS 2005	-41.20	-41.16	-41.20	-41.20	-41.20	-41.10

4.5 Identification of the core carbon tax scheme and its improvement

Based on the above analysis, within the five protective schemes, there is no such a scheme that is able to ease the negative impacts on household income and welfare, whilst will not expand the urban-rural gap. Maintaining economic growth and household living standard is especially important for such a developing country as China. In the whole period analyzed, scheme IT performs the best in this aspect. Moreover, scheme IT is one of the two schemes that can effectively reduce the expansion extent of urban-rural gap caused by carbon tax. What is more, our previous study [12] shows that, such a manner of tax revenue recycling performs best in protecting the international competitiveness of energy- and trade-intensive sectors. Therefore, scheme IT should be set as the core carbon tax scheme.

The main disadvantage of scheme IT is that it will still widen the urban-rural gap. As discussed above, without any protections for households, the main reason that taxing carbon will enlarge the urban-rural gap lies in that the share rural households obtain in transfer payments are too low. Therefore, here this study will examine whether increasing the share rural households obtain in government transfers can improve the effects of scheme IT.

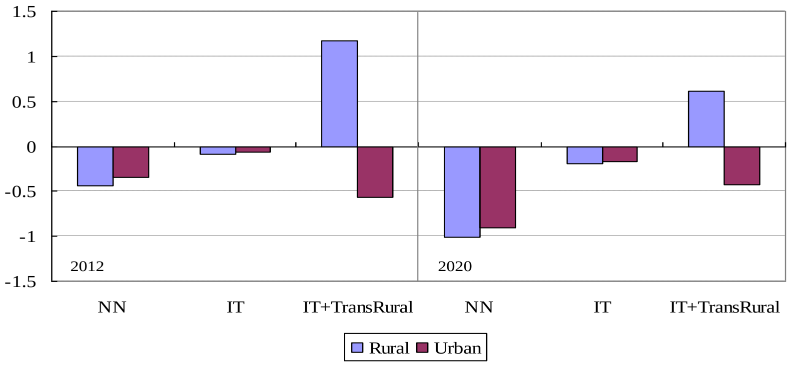

Fig. 7. Impacts on household disposable income by the improved scheme IT, scheme NN and original scheme IT (%)

Fig.7 illustrates the variations of household disposable income under the improved scheme IT (corresponding to the item IT+TransRural), which combines the original scheme IT with doubling the share rural households obtain from government transfers. Fig.7 also illustrates the corresponding variations under scheme NN and the original scheme IT. Results show that, the improved scheme IT is able to narrow urban-rural income gap compared to before the tax is levied, and there is increase in rural household income, and in the long term the negative impacts on urban households' income are smaller than the no-protection scheme. What is more, the variations of other macro-economic index under this improved scheme is similar to the original scheme IT, i.e. in the long term the negative impacts are small and increasing slowly over time.

5. Conclusions and policy implications

5.1 Conclusions

Based on the recursive-dynamic CGE model CEEPA, this study assessed the impacts of taxing carbon in China on income distribution and household living standard, and compared the effects of different ways to protect households. Main conclusions of this study are as follows:

- If no protections for households are considered, from the perspective of no matter income or expenditure, a carbon tax will reduce the living standard of both urban and rural households, and the negative impacts on rural households are greater than urban households mainly because currently urban households obtain a much greater share in transfer payments.
- Exempting households from carbon tax has weak effects either on reducing the negative impacts on households, or on preventing the expansion of urban-rural gap.
- Given the current social security system that obviously favors urban households, the two measures that can effectively reduce the extent of urban-rural gap expansion caused by taxing carbon are scheme IT and scheme LS.
- Given the current social security system that obviously favors urban households, the only scheme that can completely avoid the expansion of rural-urban gap is scheme LS. But the long-term negative impacts on household living standard under this scheme are greater than the no-protection scheme.
- Given the current investment-driven economic growth pattern, the negative impacts on household income and welfare under each scheme will increase over time. In the long term, scheme IT has obviously smaller negative impacts on household living standard and economic growth than the other schemes.
- Increasing the share rural households obtain in government transfers helps to avoid the expansion of urban-rural gap.

5.2 Policy implications

The primary elements of a tax scheme include taxpayer, tax rate, object of taxation and tax base, tax relief, revenue recycling, tax payment stage and place, tax calendar (assessed in regular periods or on a transaction-by-transaction basis) and penal clause. Discussions about the more administrative issues as tax payment stage and place, tax calendar and penal clause are beyond the scope of this study. In line with the definition of a carbon tax, and in order to facilitate management and reduce the collecting and paying cost, the object of taxation and tax base are usually set as fossil fuels and their carbon-content respectively. For the other major elements, based on the conclusions of this study, the following policy recommendations are proposed:

(1) Given the current social security system that obviously favors urban households and the current investment-driven economic growth pattern, it is necessary to introduce proper complementary measures for protecting households when designing a carbon tax scheme for China.

(2) Protections for households should mainly rely on carbon tax revenue recycling. That is, households need not be excluded from taxpayers, or be tax relieved; the revenue from carbon tax should be recycled and protection for households should be stated in the section of revenue recycling according to the prior consideration of decision makers:

- If the current investment-driven economic growth pattern sustains, an ideal manner of revenue recycling, which can not only avoid the expansion of urban-rural gap, but also reduce the negative impacts on households in the long-term, is using carbon tax revenue to reduce indirect tax, but should at the same time increase the share rural households obtain in government transfers. Actually, China is now promoting reforms such as the new rural cooperative medical care system and the new rural social insurance system, which are gradually creating a favorable environment for such a manner of revenue recycling.

- Reforms in social security are time-consuming, thus if avoiding the further expansion of rural-urban gap is highly emphasized, given the current unreasonable distribution status, carbon tax revenue could be transferred to households in proportion to the population. However, if the current investment-driven economic growth pattern sustains, such a manner of revenue recycling should not be used as a sole long-term policy: either should other measures for increasing household income be designed and promoted concurrently, or the manner should finally turn to reducing indirect tax with carbon tax revenue.

(3) When incorporating the measure of reducing indirect tax rate with carbon tax revenue, if a total amount control goal is adopted, the applicable tax rate should be higher than it would be under a no-protection scheme; while if an emission intensity goal is adopted, there is no need to adjust the applicable tax rate.

(4) When incorporating the measure of transferring carbon tax revenue to households in proportion to the population, the applicable tax rate need not be adjusted either under a total amount control goal or an emission intensity goal.

6. Further perspectives

The distributional impacts of carbon taxes may be measured across different dimensions, e.g. between households over different income groups, between different household types, between rural and urban households, and between different generations [10]. Due to the problem of data availability, this study has just performed a preliminary analysis on the distributional effects between rural and urban households. Being a large developing country, besides obvious urban-rural gap, China has obvious discrepancies among different income groups and among different regions. Especially, results of this study shows that, the impacts on urban households are negative even under the improved scheme IT, and these negative impacts are greater than those under the original scheme IT. That is, the expansion of urban-rural gap is avoided at the expense of general living standard of urban households. However, there exist different income groups within urban households. Then, will the increase in negative impacts on urban households fall more on its inner low-income groups? Wang's study [17] shows that this situation is possible to happen if no protective measures is applied. Then, if complementary measures for protecting households are taken into account, and from the perspective of general equilibrium, what will the case be? Two important aspects of our future work are to examine the distributional impacts of carbon taxes between households over different income groups and different regions.

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