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RESEARCH ARTICLE

On the distributional impact of a carbon tax in developing countries: the case of Indonesia

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Abstract This paper, using a computable general equilibrium model with highly disaggregated household groups, analyses the distributional impact of a carbon tax in a developing economy. Indonesia, one of the largest carbon emitters among developing countries, is utilized as a case study in this paper. The result suggests that, in contrast to most industrialised country studies, the introduction of a carbon tax in Indonesia is not necessarily regressive. The structural change and resource reallocation effect of a carbon tax is in favour of factors endowed more proportionately by rural and lower income households. In addition, the expenditure of lower income households, especially in rural areas, is less sensitive to the price of energy-related commodities. Revenue-recycling through a uniform reduction in the commodity tax rate may reduce the adverse aggregate output effect, whereas uniform lump-sum transfers may enhance progressivity.

Keywords Climate change · Carbon tax · Environmental economics

1 Background

Global warming has become an alarming problem as scientific studies now show more conclusively that it is a man-made disaster (Stern 2007). The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report in 2007 stated that emissions of greenhouse gases (GHG's) have increased since the mid-

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nineteenth century and are causing significant and harmful changes in the global climate (IPCC 2007). Despite these concerns, multilateral action for greenhouse gas stabilisation has been difficult to implement, mainly because of the belief that such action is associated with high costs and unfair (or regressive) distributional impacts; i.e. it would tend to hurt the poorest countries more and, within a country, impose a disproportionate burden on poor households.

Developing countries are increasingly contributing to the accumulation of greenhouse gases, even though their per-capita carbon emission is still far lower than that of developed countries. Developing countries already account for half the total annual greenhouse gas emission, and in the future, emission growth will mainly be attributed to them (Jotzo 2005). Hence the participation of developing countries in curbing global greenhouse gas emission is crucial and could be the important driver needed to resume to the ‘halting progress’ of multilateral efforts. However, in addition to concerns over the economic growth impact of climate policy, they fear an undesirable distributional effect of such policy, particularly the possibility of increased poverty and inequality.

Literature from developed countries suggests there is a conflict between environmental and equity objectives in the case of carbon abatement policies, for example, that a carbon tax has mostly proved to be regressive, i.e. its cost is borne more by lower rather than higher income households (Poterba 1991; Hamilton and Cameron 1994; Baranzini et al. 2000). On the other hand, with regard to developing countries, the evidence of this, if any, has been limited. While the efficiency gain of environmental policies has been widely researched, it is hard to find studies that assess its distributional impact outside industrialised countries. Given the general tendency in the literature, it would be interesting and relevant to know whether a similar conclusion could be drawn with regard to developing countries. Shah and Larsen (1992) indicated that there are many characteristics of developing countries such as industrial characteristics and household expenditure patterns that could point to such policies not being regressive. Figure 1, for example, illustrates how different the expenditure patterns of Europeans and Indonesians are (as a percentage of total expenditure) with regard to energy and energy intensive items. With the exception of transportation and vehicle purchases, the expenditure patterns are relatively different. Hence, it is important to examine whether or not and to what extent this expectation can be demonstrated empirically.

Indonesia is utilised as the case study in this paper. As the fourth largest country in terms of population, an increase in its emissions per capita would most likely significantly increase the total global emissions, Indonesia’s position is an important factor in global climate change policy. In the mid 2000s, Indonesia was one of the top 3–5 emitters of CO_2 as a result of deforestation and forest degradation; without this aspect, it is ranked 16th or lower. Among developing countries, Indonesia ranks 7th in total CO_2 emission from fossil fuel and ranks 2nd, after China, if CO_2 emission from land use change is included (Sari et al. 2007). The ability of Indonesia to control emissions is therefore of great global concern.

It is important to note regarding the case of Indonesia that, while emissions from the forestry sector tend to be declining, if not steady, in future, due to the declining size of forest cover, emission from fuel combustion is expected to

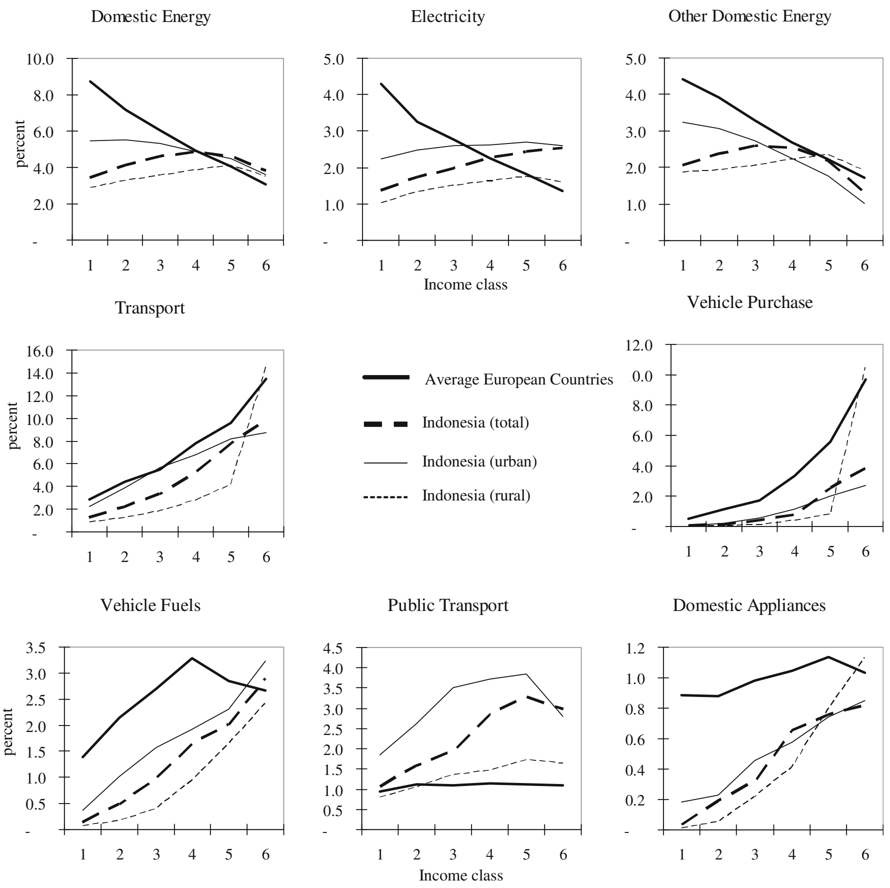

Fig. 1 Household expenditure patterns (in percentage of total expenditure) on energy and energy intensive items in Europe and Indonesia in 1990s. *Horizontal axis* is income classes from the poorest to the richest; i.e. *1* the poorest and *6* the riches classes. Source: Kohler et al. (1999) and Indonesian National Socio-Economic Survey (SUSENAS)

increase significantly and to overtake that of the forestry sector soon. The main reasons for this are the increasing consumption and changing composition of the Indonesian energy mix (Resosudarmo et al. 2011; Nurdianto and Resosudarmo 2011). Although emission from the consumption of liquid petroleum products still dominates, amounting to approximately 53 % of Indonesia's mid 2000s fossil-fuel CO_2 emissions, emission from coal usage has risen steadily from comprising only 1 % in the early 1980s to approximately 26 % in the mid 2000s. The priority of coal as fuel for electric power generation has become Indonesia's future agenda as oil runs out.

Hence, this paper focuses its analysis on the distributional impact of a carbon tax implemented on energy sources (among others are coal, gasoline, automotive diesel oil, kerosene and natural gas); in particular whether the distributional impact is regressive or progressive.[1] A computable general equilibrium (CGE) model fully integrating two hundred households is utilised in this paper. This type of CGE is rare in that it can simultaneously take into account both income and expenditure patterns as inseparable driving forces in the distributional outcome; and also allows for more direct and accurate calculation of inequality indicators and poverty incidences. The outline of this paper is as follows. After the introduction, there is a literature review on the distributional impacts of carbon abatement policies. A description of the CGE model developed for this paper follows, then the policy simulation and discussion sections, followed by a conclusion.

1.1 Distributional impact of a carbon tax

Most of the studies on the distributional impact of a carbon tax are of developed countries, as is observed by Baranzini et al. (2000). Among the early works is that of Poterba (1991) who analyses the distributional effect or a carbon tax by examining the expenditure pattern of households, especially the pattern of energy spending in the United States of America (US). Other earlier works include studies by Pearson and Smith (1991) and Hamilton and Cameron (1994). Pearson and Smith (1991) examined the distributive effect of a carbon tax in European countries. Hamilton and Cameron (1994) estimated the distributional impact of meeting the Rio target for Canada, stabilising CO_2 emission at the 1990 level by the year 2000. The more recent studies on this subject in developed countries are, among others, conducted by Brannlund and Nordstrom (2004), Oladosu and Rose (2007), Leach (2009) and Callan et al. (2009). Most of these studies confirm that a carbon tax or energy tax in developed countries is regressive.

For developing countries, among the few are works by Shah and Larsen (1992), Brenner et al. (2007), Corong (2008) and Ojha (2009). For the case of Pakistan, Shah and Larsen (1992) noted that a \$10 per ton carbon tax burden falls with income, thereby yielding a regressive pattern of incidence. Such regressivity is nevertheless less pronounced with respect to household expenditure. Ultimately, Shah and Larsen (1992) concluded that the regressivity of carbon taxes should be less of a concern in developing than in developed countries.

Brenner et al. (2007) analyse the distributional impacts of carbon charges and revenue recycling in China using the data of a nationally representative household income and expenditure survey for the year 1995. They separate household spending into six categories, and apply a carbon loading factor to each of the categories to estimate the carbon usage embodied in these different types of household consumption. Their results suggest that the effect of a carbon charge of 300 Yuan per metric ton of carbon would be progressive, even without revenue recycling. Brenner et al. (2007) conclude that the results are primarily driven by differences between urban and rural expenditure patterns, and also conjecture that a similar pattern may exist in other developing countries.

Corong (2008) implemented a combination of CGE and household micro-simulation models to analyse the impact of a carbon tax on the economy of the

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[1] It is true that currently the forestry sector produces the highest CO_2 emissions in Indonesia. However, forest emission is different from fossil fuel combustion emission caused by the use of fuels by various economic sectors for their energy inputs.

Philippines and on the livelihood of its people. The carbon tax in this paper is an ad valorem tax on different fuel types which is equivalent to 100 pesos (or approximately $2.3) per ton of carbon emission. This study suggests that a carbon tax would compensate for any tariff revenues lost through a reduction in trade tariffs during an ongoing trade liberalisation process in the Philippines, at the same time reducing poverty and increasing public welfare.

The same methodology, i.e. a combination of CGE and household micro-simulation models, was implemented by Ojha (2009) for India. This work suggests that a domestic carbon tax policy that recycles carbon tax revenues to households imposes heavy costs in terms of lower economic growth and higher poverty. However, such effects can be minimised if the emissions restriction target is modest, and carbon tax revenues are transferred exclusively to the poor.

The literature demonstrates that the distributional impact of a carbon tax on developing countries, though some have indicated it to be progressive, is less conclusively so than for developed countries. Many developing countries, though not exactly the same, share relatively similar industrial characteristics and household expenditure patterns (Shah and Larsen 1992; Todaro and Smith 2011). More work is certainly needed in the case of developing countries before arriving at a more definite conclusion that the distributional impact of a carbon tax on developing countries tends to be progressive. If it does tend to be progressive, then developing countries do not have to be concerned that implementing a carbon tax policy will place a disproportionate burden on the poor and increase inequality.

2 The computable general equilibrium model

2.1 Model structure

The CGE model in this paper is based on an ORANI-G model, an applied general equilibrium model of the Australian economy. Its theoretical structure is typical of a static general equilibrium model which consists of equations describing (1) producers' demands for produced inputs and primary factors; (2) producers' supplies of commodities; (3) demands for inputs to capital formation; (4) household's demand system; (5) export demands; (6) government demands; (7) the relationship of basic values to production costs and to purchasers' prices; (8) market-clearing conditions for commodities and primary factors; and (9) numerous macroeconomic variables and price indices (Horridge 2000). Demand and supply equations for private-sector agents are derived from the solutions to the optimisation problems (cost minimisation and utility maximisation) which are assumed to underlie the behaviour of the agents in conventional neoclassical microeconomics. The agents are assumed to be price-takers, with producers operating in competitive markets with zero profit conditions. The important features of the model that also involve significant modifications to the standard ORANI-G model are as follows.[2]

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[2] Please see Horridge (2000) for the ORANI-G model. Detailed equations of the model utilised in this paper can also be seen in Yusuf (2008).

The first modification is to allow substitution among energy commodities, and also between primary factors (capital, labour, and land) and energy. Figure 2 shows the modified structure of production in the model. In this respect, this model has 38 industries, and 43 commodities. Fossil-fuel commodities include coal, natural gas, gasoline, automotive diesel oil, industrial diesel oil, kerosene, and liquefied petroleum gas (LPG). The utilization of nested constant elasticity of substitution (CES) production functions allows industries to change their mix of inputs in response to changes in commodity prices.

Second, the model incorporates carbon (CO_2) emission accounting, and a carbon taxation mechanism (Adams et al. 2000). In this paper, only CO_2 emission from fossil fuel combustion is included. Other sources of CO_2 emission such as land-use change or deforestation are excluded. Statistics of Indonesian Energy Balance reports provide details of consumption of fossil-fuel (natural gas, coal, gasoline, diesel, kerosene, LPG, other) in barrels of oil equivalent (BOE). From this data, the amount of CO_2 emission is calculated. Then, after taking into account the different prices paid by households and industries due to the fuel subsidy and using the social accounting matrix data that provides details of consumption of fossil-fuel by various industries and households and by type of fossil-fuel, a matrix of CO_2 emissions by fuel type and by users (industry and households), or $E_{f,u}$, can be calculated. More specifically,

$$E_{f,u} = \alpha \cdot \varpi_f \cdot CC_f \cdot \phi \cdot Q^E_{f,u} \tag{1}$$

where $E_{f,u}$ is the CO_2 emission by fuel type f, used by user u, in tons; $Q^E_{f,u}$ is the quantity of fuel consumption by fuel type f, used by user u, in energy units (BOE); ϕ is a factor to convert BOE to Giga-Joule; CC_f is the carbon content of fuel type f in tons of carbon per Giga-Joule (tC/GJ), ϖ_f is the oxidation factor by fuel type i.e. fraction of carbon oxidised, and α is a constant. $Q^E_{f,u}$ data is from Statistics of Indonesian Energy Balance 2003, whereas ϖ_f, CC_f, ϕ are from the database of the International Panel on Climate Change (IPCC).

Following Adams et al. (2000), government revenue from a carbon tax, R, can be calculated as,

$$R = \tau \cdot \sum_f \sum_u E_{f,u} \tag{2}$$

where τ is a specific tax on CO_2 (in Rupiahs per ton of CO_2), and $E_{f,u}$ is the quantity (tons) of emission of CO_2 by fuel type f and by user u. Since the emission tax will be imposed as an ad-valorem energy/fuel tax, R will be equivalent to

$$R = \sum_f \sum_u \frac{t_{f,u}}{100} P_f Q_{f,u} \tag{3}$$

where t_f is the ad-valorem tax rate, P_f is the price, and $Q_{f,u}$ is the quantity of fuel consumed by user u. For every fuel type and user, a specific emission tax can be translated into an ad-valorem fuel tax as follows:

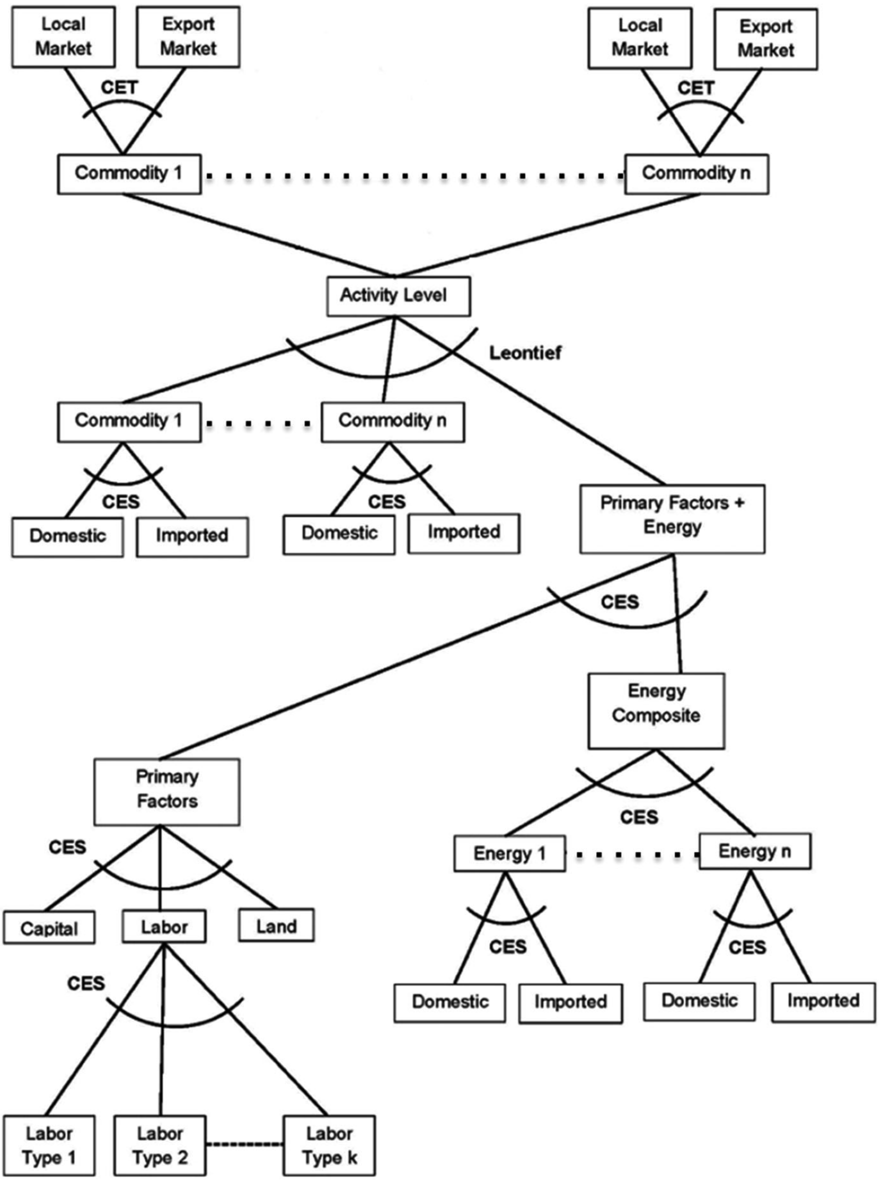

Fig. 2 Structure of production

$$t_{f,u} = \tau \frac{100 \cdot E_{f,u}}{P_f \cdot Q_{f,u}} \tag{4}$$

The last part of the equation, $\frac{E_{f,u}}{P_f \cdot Q_{f,u}}$, can be defined as emission intensity per Rupiah use of fuel. To determine the price of carbon (or carbon tax), the impact on the ad-valorem tax rate for each type of fuel not only depends on technical, or chemical matter such as its carbon content, but also on economic variables or market conditions such as its price.

Third, a multi-household feature is added to the standard model which only includes single households. The multi-household feature is not only added to the expenditure or demand side of the model, but also to the income side.

2.2 Social accounting matrix

The 2003 Indonesian Social Accounting Matrix serves as the core database for the CGE model. The distributional impact of policies analysed in the CGE modelling framework has been constrained in part by the absence of a Social Accounting Matrix (SAM) with disaggregated households. Since the official Indonesian SAM does not distinguish households by income or expenditure size, it has prevented accurate assessment of the distributional impact, such as calculation of inequality or poverty incidence. The SAM used in this paper is a specially constructed SAM representing the Indonesian economy for the year 2003, with 200 households (100 urban and 100 rural households grouped by expenditure per capita centiles). Constructing a specifically designed SAM with distributional emphasis not only requires large-scale household survey data but also involves the reconciliation of various different data sources.

The SAM used in this model not only provides detailed household disaggregation, but also detailed labour classification acknowledging the typical characteristics of labour markets in developing countries like Indonesia. It distinguishes 16 classifications of labour; it recognises 4 types of skills (agricultural, non-agricultural unskilled, clerical and services, and professional workers); and distinguishes between urban and rural, and formal and informal (unpaid) workers.[3]

2.3 Closure and parameters

This paper is interested in conducting relatively short to medium-term analysis and so the following closures are chosen. On the aggregate demand side, aggregate real investment, aggregate real government consumption, and trade balance (in real terms) are treated as exogenous, whereas aggregate real household consumption is endogenous and hence can be interpreted as the aggregate index of welfare. Household and government savings as well as net savings abroad are set to be free. The nominal exchange rate is the numeraire.

On the factor market closure side, capital is specific, cannot move across sectors,[4] and the industry-specific price of capital is the equilibrating variable. Labour is mobile across industries; however aggregate employment is exogenous, a typical neoclassical closure with full employment.[5]

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[3] For detailed information on how the SAM utilised in this paper is constructed, see Yusuf (2006).

[4] Or other interpretation of this closure is that capital mobility is happening only among industries within each sector classification in this paper.

[5] Indonesia's labour force mostly consists of informal labour with flexible wages. The unemployment level in Indonesia is relatively stable. Based on this situation, the interpretation of full employment in this model is that the level of unemployment is stable or constant.

The set of parameters in the CGE model are: (1) Armington elasticity between domestic and imported commodities; (2) export elasticity; (3) elasticity of substitution among labour types (or skills); (4) elasticity of substitution among primary factors; (5) constant elasticity of transformation for industries with multiple commodities; (6) elasticity of substitution among energy types; (7) elasticity of substitution between energy composite and primary factor; (8) expenditure elasticity for LES household demand system, and; (8) Frisch parameter, elasticity of marginal utility of income.

Parameters 1 and 4 are taken from the GTAP database. Parameter 2 is assumed to be twice of parameter 4 (Jomini et al. 1991; Liu et al. 2004). Parameters 3, 5, 6 and 7 are borrowed from the INDOCEEM model, a model developed by Monash University and the Indonesian Ministry of Energy and Mineral Resources (Said et al. 2001; Ikhsan et al. 2005).[6] Here, the elasticity of substitution among fossil-fuel inputs is set moderately at 0.25, while the elasticity of substitution between energy composite and primary factors of production is set at 0.1. The choice of these substitution numbers, more or less, represents a short to medium run situation in Indonesia. All of the parameters borrowed from literature or other models are subject to sensitivity analysis as discussed in the Appendix 1 section. Expenditure elasticity parameters are estimated econometrically, and the Frisch parameter is calculated based on the study by Lluch et al. (1977).

2.4 Method for analysing distributional impact

There are various approaches for dealing with income distribution analysis in a CGE model. The most common studies for Indonesia are CGE studies that use the official household classification of the SAM, i.e., 10 socioeconomic classes. The distributional impact is only analysed by comparing the impact of policies among these socioeconomic classes. Studies by Resosudarmo (2003) and Azis (2006), among others, follow this approach.

The modification of the above method is the representative household method, where it is assumed income or expenditure of households follows a certain functional form of distribution. Distribution is assumed to remain constant before and after the shock. This approach means the behaviour of the group is usually dominated by the richest households. There has been growing evidence to suggest that variation within a single household-category is important and can significantly affect the results of the analysis (Decaluwé et al. 1999).

Another approach is a top-down method, where price changes produced by the CGE model are transferred to a separate micro-simulation model, such as a demand system model or an income-generation model. Price changes are exogenous in this micro-model, hence, endogeneity of prices is ignored. Belonging to this category among others are studies by Filho and Horridge (2006) on Brazil, and Savard (2003) on the Philippines. Bourguignon et al. (2005) developed this type of approach for Indonesia.

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[6] More information on the INDOCEEM model can be seen at the website of Centre of Policy Studies (http://www.copsmodels.com/archivep.htm#tpmh0032).

An improvement on the above method is an approach that allows the model to take into account the full details from household-level data, and avoids pre-judgment about aggregating households into categories. All prices are endogenously determined by the model, and no prior assumption of parameter distribution is necessary. This integrated micro-simulation-CGE model has been implemented in various studies including Annabi et al. (2005) for Senegal, Plumb (2001) for UK, and Cororaton and Cockburn (2006) for the Philippines.

The last approach is disaggregating or increasing the number of household categories by the size of expenditure or income per capita. In this approach, ideally, all observations in the household survey are integrated in the model as in the micro-simulation CGE models. However, this is computationally challenging. Limiting the number of household categories, but still keeping it large enough, seems to be the best approach. The CGE developed for this paper hence adopts this approach; i.e., a CGE with 100 urban and 100 rural households.

In this paper, poverty incidence is simply calculated using the following formula. Let y_c represent real expenditure per capita of a household of the c-th centile where $c = 1,\ldots, n$. Let the poverty line be y_p which lies between two levels of real expenditure per capita within c; i.e. the largest real expenditure per capita that is still lower than the poverty line or $\max\{y_c|y_c < y_p\}$ and the smallest real expenditure per capita but above the poverty line or $\min\{y_c|y_c > y_p\}$. Thus, poverty incidence is calculated using

$$P(y_c, y_p) = \max\{c|y_c < y_p\} + \nabla c \tag{5}$$

where, $\nabla c = \frac{y_p - \max\{y_c|y_c < y_p\}}{\min\{y_c|y_c > y_p\} - \max\{y_c|y_c < y_p\}} \cdot (\min\{c|y_c > y_p\} - \max\{c|y_c < y_p\})$.

The first term in Eq. (5) is simply the centile where real expenditure per capita is lower than the poverty line; i.e. number of households with real expenditure per capita lower or equal to $\max\{y_c|y_c < y_p\}$ (Fig. 3). The second term is the linear approximation of the number of households with real expenditure per capita above $\max\{y_c|y_c < y_p\}$ but still lower than the poverty line.

The change in poverty incidence after a policy shock (simulation) is calculated as $\Delta P = P(y'_c, y_p) - P(y_c, y_p)$ where $y'_c = \left(1 + \frac{\hat{y}_c}{100}\right) \cdot y_c$ and $\hat{y}_c$ is the percentage change in real per capita expenditure of a household of the centile c produced from the simulation of the CGE model. The change in the real expenditure per capita across households will be used to investigate ex-ante distribution (before the policy change) and ex-post distribution (after the policy change).

3 Simulation scenarios

In this paper, a carbon tax of Rp. 280,000 (or approximately \$30) per ton of CO_2 emission, which should be high enough to stabilise Indonesian emissions in the short-term, is introduced with three different scenarios of revenue-recycling. Note that the main goal of this paper is to observe the direction of distributional impacts

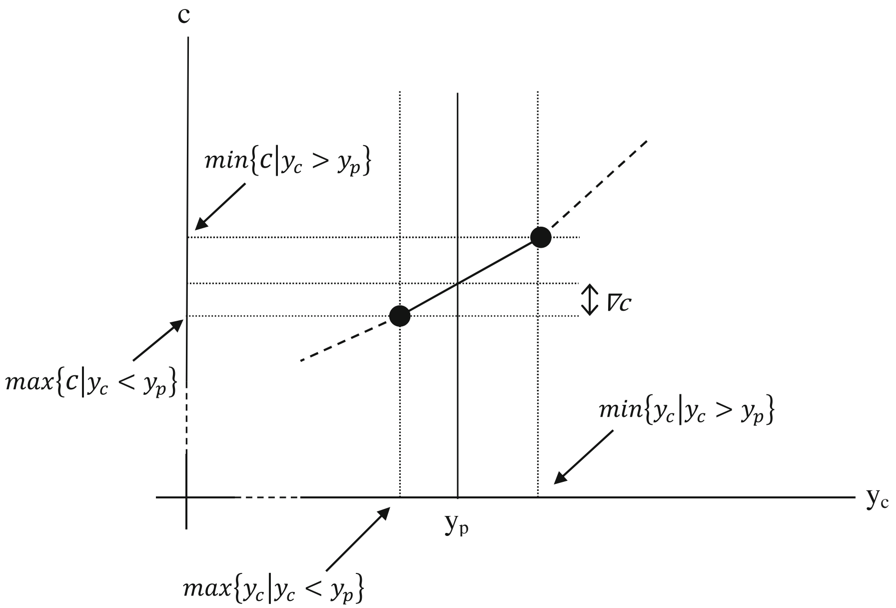

Fig. 3 Cumulative distribution of household real expenditure per capita

of a carbon tax. Choosing other carbon tax rates will probably not change the direction of the distributional impact generated by the currently implemented scenarios.

In the first scenario (SIM 1), a carbon tax is implemented without revenue recycling, that is the revenue from the carbon tax is assumed to be used for fiscal adjustment, allowing government to run a budget surplus. This is intended to reveal the direction of the distributional cost, if the tax revenue is not returned to the economy or is not used for compensation.

The following two options will be considered for revenue-recycling, in order for the carbon tax policy to be "revenue-neutral". In the second scenario (SIM 2), the implementation of the carbon tax will be accompanied by a reduction in a uniform general ad-valorem sales tax rate for all commodities, such that extra government revenue disappears. To do this, a uniform sales tax shifter is endogenised while government saving is exogenised. The other relevant scenario using a revenue-recycling mechanism is to make a uniform lump-sum transfer to all households. This will be the third scenario (SIM 3).

There are certainly many other scenarios which could be developed. The three scenarios above have been chosen for their simplicity and should be able to highlight the distribution impact of a carbon tax policy. Please note that Appendix 2 provides alternative scenarios in which the three scenarios mentioned above are implemented with a similar carbon reduction target; i.e. a reduction of 6 % from the initial condition.

4 Results and discussion

4.1 Macroeconomic and industry results

The summary of macroeconomic, emission, and factor market results is shown in Table 1. Tables 2 and 3 present the results concerning industry output and the prices of several relevant commodities.[7]

The immediate effect of introducing a carbon tax is an increase in the price of energy products because it is implemented through an increase in the ad-valorem tax on energy commodities, the magnitude of which depends among other things on their carbon content. The price of coal increases the most by more than 100 %, followed by other energy sources (Table 3). There are two possible reactions by industries to increasing prices in energy sources: (1) substituting high carbon content energy with lower carbon content energy, and/or (2) reducing their energy consumption by lowering their output. Hence, the impact of increasing the price of energy sources varies depending on the industry. The higher the energy intensity of an industry, the greater the correction.

The industries that suffer the most are obviously the energy related sectors (Table 2). In SIM 1, for example, petroleum refinery and coal mining outputs fall by 3.9 and 2.9 %, respectively. Non-energy sector industries that experience a significant decline in their outputs are those that are relatively highly energy intensive, such as the chemical product, pulp and paper, non-ferrous metal, electricity, water and gas, construction, and transportation industries. On the other hand, industries that are relatively less energy intensive, such as crops and forestry, are less affected or could even gain from this tax implementation. Nevertheless, since the contraction is generally much larger than the gain, the direct impact of a carbon tax would be a contraction of the economy.

Each revenue-recycling policy would have its own particular impact on the economy. In general any revenue-recycling policy, i.e. either through uniform reduction in the commodity tax rate (SIM 2) or uniform cash transfers to all households (SIM 3), softens the impact of a carbon tax. SIM 2, in which revenue from a carbon tax is returned to the economy as a uniform reduction in the commodity tax rate, has the least damaging impact on welfare. A reduction in the commodity tax rate minimises the impact on prices of commodities following a carbon tax implementation, as can be seen by the lowest percentage increase in the consumer price index. This has an expansionary effect on the economy because of a greater increase in demand and output for commodities than that achieved by uniform cash transfers to all households.

In all scenarios in this paper, ultimately, the combination of a contraction impact due to a carbon tax and an expansionary impact due to revenue cycling results in a slight contraction of the economy.

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[7] The model utilized in this paper is a static model, not a dynamic CGE model. Hence, the results do not show any information on dynamic adjustment to the new equilibrium; such as how long it will take for the new equilibrium to be reached.

Table 1 Macroeconomic, emission and factor market results of carbon tax policies (in %age change)

	SIM 1 No-revenue recycling	SIM 2 Uniform cut on com. tax rate	SIM 3 Uniform transfers
Macroeconomics			
GDP	−0.04	−0.02	−0.03
Consumption expenditure	−0.06	−0.03	−0.04
CPI	1.32	0.58	1.75
Export	−0.11	0.67	−0.12
Import	−0.16	0.93	−0.16
CO_2 emission	−6.55	−6.39	−6.52
Real wage			
Agriculture, rural, formal	−0.58	1.62	1.28
Agriculture, urban, formal	−0.54	1.78	1.48
Agriculture, rural, informal	−0.48	1.63	1.61
Agriculture, urban, informal	−0.49	1.7	1.63
Production, rural, formal	−2.68	2.03	−2.73
Production, urban, formal	−4.65	0.56	−5.21
Production, rural, informal	−2.23	2.25	−2.55
Production, urban, informal	−2.24	2.22	−2.98
Clerical, rural, formal	−2.17	1.49	−2.92
Clerical, urban, formal	−3.12	0.66	−4.1
Clerical, rural, informal	−1.76	2.11	−1.64
Clerical, urban, informal	−1.78	2.05	−1.93
Professional, rural, formal	−3.19	0.5	−4.32
Professional, urban, formal	−3.55	0.54	−4.63
Professional, rural, informal	−2.19	1.49	−2.72
Professional, urban, informal	−2.06	2.46	−3.45
Average return to capital	−5.77	−1.86	−6.23
Average return to land	−0.41	1.81	1.78

com. tax rate commodity tax rate

Gross domestic product (GDP) and consumption expenditure, which are indicators of aggregate welfare, reduce slightly in all three scenarios (Table 1).

At the industrial level, however, some industries experience an expansionary output, but some others a contraction (Table 2). Carbon tax changes the structure of the industry in the economy.

4.2 Distributional results

Figure 4 illustrates in greater detail how each simulation affects household income per capita, household specific consumer price index (CPI), and household real

Table 2 Impact of carbon tax policies on industrial outputs (in %age change)

	SIM 1 No-revenue recycling	SIM 2 Uniform cut on com. tax rate	SIM 3 Uniform transfers
Output of industries			
Paddy	0.09	0.09	0.29
Other food crops	0.05	−0.09	0.09
Estate crops	−0.13	−0.08	−0.38
Livestock	0.13	0.14	0.35
Wood and forests	0.09	0.15	0.05
Fish	−0.08	−0.03	−0.02
Coal	−2.94	−2.88	−2.95
Crude oil	−0.29	−0.3	−0.28
Natural gas	−0.69	−0.69	−0.69
Other mining	−0.1	−0.23	−0.08
Rice	0.1	0.1	0.31
Other food (manufactured)	0.15	0.18	0.58
Clothing	0.41	0.96	0.64
Wood products	0.23	0.33	0.04
Pulp and paper	−0.07	0.17	−0.14
Chemical product	−0.66	−0.27	−0.41
Petroleum refinery	−3.87	−4.01	−3.83
LNG	−2.89	−2.83	−2.89
Rubber and products	−0.2	0.54	−0.51
Plastic and products	−0.05	0.46	0.07
Nonferrous metal	−1.61	−1.93	−1.49
Other metal	−0.37	−0.12	−0.28
Machineries	−0.5	2.45	−0.22
Automotive industries	0.35	−0.08	−0.47
Other manufacturing	0.2	0.38	0.76
Electricity	−1.44	−1.32	−1.29
Water and gas	−2.24	−2.13	−2.68
Construction	−0.01	−0.01	−0.02
Trade	0.05	0.09	0.29
Hotel and restaurants	0.3	0.1	0.24
Road transportation	−0.66	−0.67	−0.58
Other transportation	−1.44	−1.29	−1.43
Banking and finance	0.23	0.02	0.1
General government	–	–	–
Education	0.11	0.06	0.04
Health	0.31	0.17	0.49
Entertainment	0.6	0.49	0.23
Other services	0.29	0.04	−0.25

com. tax rate commodity tax rate, *LNG* liquefied natural gas, – trivial

Table 3 Impact of carbon tax policies on commodity prices (in %age change)

	SIM 1 No-revenue recycling	SIM 2 Uniform cut on com. tax rate	SIM 3 Uniform transfers
Prices of commodities			
Coal	131.8	131.95	132.47
Natural gas	26.35	27.27	26.5
Gasoline	24.61	24.72	24.59
Diesel (automotive)	45.31	45.56	45.44
Diesel (industries)	43.48	43.83	43.67
Kerosene	29.3	29.54	29.93
LPG	25.62	26.28	24.71
Other fuels	21.37	21.9	21.46
Electricity	16.93	16.97	17.38
Water and gas	12.38	12.13	12.16
Road transportation	1.77	1.3	1.58
Other transportation	2.36	1	2.31
CPI	1.32	0.58	1.75

com. tax rate commodity tax rate, *LPG* liquefied petroleum gas, *CPI* consumer price index

expenditure per capita across urban, rural, and expenditure classes. The relationship between changes in real expenditure, income and CPI is as follows:

$$\Delta X \approx \Delta Y - \Delta P \tag{6}$$

where ΔX is the percentage change in real household expenditure per capita, ΔY is the percentage change in household income per capita and ΔP is the percentage change in CPI. Poverty and Gini coefficients are calculated using household expenditure, and the channels through which carbon tax policies affect real expenditure are the change in household income and commodity prices or household specific CPI.

All graphs in Fig. 4 rank each centile of households from the poorest to the richest on the x axis. The y axis is the percentage change of each indicator (household real expenditure and income as well as CPI). Therefore, for example, the top left graph shows that the poorer the rural household, the higher the increase in their real expenditure. Even rich rural households face a declining expenditure. For urban households, all face a slight uniformly declining real expenditure.

Figure 4 shows that almost all rural households experience a welfare gain as their real expenditure per capita rises. These gains are distributed progressively, as poorer households gain a greater percentage change in welfare compared to richer households. On the other hand, for urban households, both SIMs 1 and 2 shows that they are worse off, and the costs are distributed relatively neutrally or slightly progressively in the case of SIM 2. For SIM 3, the lowest 20 % are better off, and the distributive effect is progressive.

The driving forces of these results are the nature of the impact of a carbon tax on both commodity prices and factor prices, in which each household has distinct

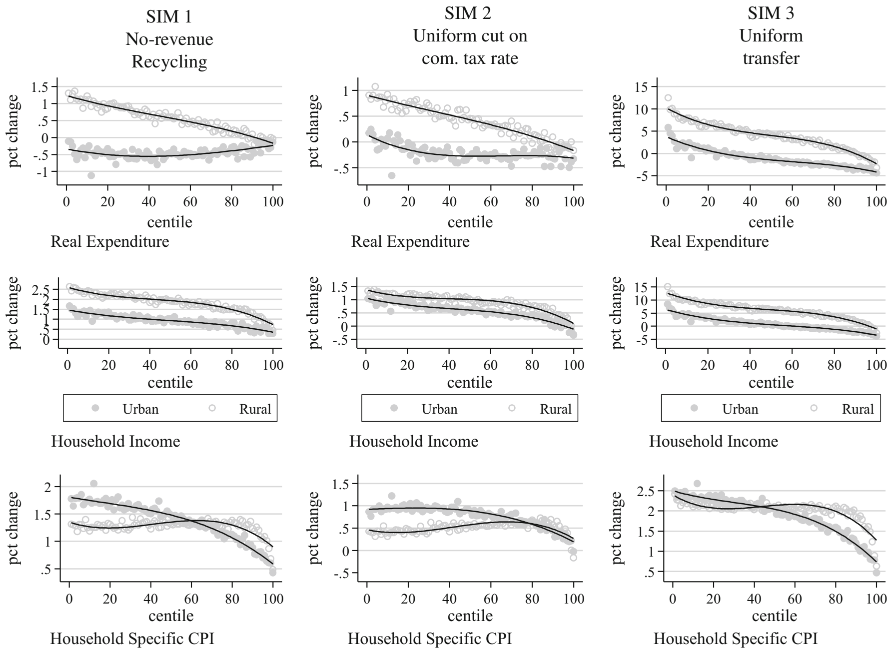

Fig. 4 Impact of carbon tax policies on households' real expenditure and income, and household specific CPI (consumer price index)

patterns of factor endowments, which then generates a pattern of household income and consumption.

One of the contributing features of the CGE model with full-integration of disaggregated households is that we can examine what causes the distributive effect from two angles. The changes in industry structure, mentioned in the previous section, reveal that there will be factor reallocation from energy-intensive sectors (which are mostly also capital intensive) into less energy and capital intensive sectors such as agriculture; i.e. factor reallocation occurring in the economy is biased against capital and skilled labour, in favour of the agricultural and services sectors. Expansion in these sectors will induce favourable changes of returns to factors of endowment in these sectors, namely agricultural, unskilled, and informal workers. For example, the return to land, and the return to informal, unskilled, rural, agricultural work rises relative to return to capital or return to formal skilled work. In other words, the changes in industry structure will affect the functional distribution of income, by a tendency to reduce returns to capital more than to other factors, and in turn will tend to have a greater proportional effect on households that are endowed with capital. The changes in the return to factors, as shown in Table 1, clarify these points. SIM 1, for example, shows that real average returns to capital fall the most by 5.77 %, while returns to land fall by only 0.41 %, and the fall in real wages varies depending on skills, but considerably less than the fall in returns to capital. Real wages fall more for urban and formal skilled labour, reflecting the contraction in the industries which employ those types of labour more intensively. On the other hand, agricultural labourers only experience a slight fall in their real wages (Table 1).

This explains why the distributive effect is progressive from the income side of households. As can be seen from the figures (middle row graph), in all scenarios the percentage change in household incomes is clearly progressive both in rural and urban areas, with overall rural household income per capita increasing more than urban household income per capita.

From the consumption perspective, in urban areas, household specific CPIs decline over expenditure centile in urban areas, suggesting that the consumption basket price increases more for poorer households than for richer ones. This is probably because although poorer households might consume less energy than richer households—i.e., electricity usage is low, and car or vehicle ownership, for example, is not as common as in richer countries—they allocate a higher proportion of their expenditure to energy and energy intensive commodities than do richer households.

This regressivity of household specific CPIs does not apply to rural households up to the 80th centile. This indicates that rural household consumption is less sensitive to the price of energy-related products than that of urban households.

The regressivity from the expenditure side and the progressivity from the income side, in turn, drive the relatively neutral, or slightly progressive—under SIMs 2 and 3—distributive effect of a carbon tax in urban areas and much more progressive pattern in rural areas. The overall nation-wide distributional impact, however, is still progressive.

Table 4 shows the summary of the distributional effect of a carbon tax for all 3 scenarios. In this table, both the poverty effect, indicated by the change in head count poverty incidence, and the inequality effect, indicated by a change in Gini coefficients, are shown for urban, rural, and all households.

With regard to the poverty impact, since rural households (especially lower income ones) experience an increase in real expenditure, poverty in rural areas falls in all scenarios. As expected, rural poverty falls the most (by approximately 4 %) when the revenue from a carbon tax is returned to households as uniform lump-sum transfers. Because the rural population is considerably larger than the urban population, declining poverty incidence in rural areas helps nation-wide poverty incidence to fall in all simulations, despite slightly increasing poverty incidence in urban areas (for SIM 1 and SIM 2).

In general, one can say that the introduction of a carbon tax in Indonesia affects urban more than rural households. In rural areas its impact is progressive, which means the poor gain relatively more than the rich. In urban areas, its distributional direction depends on how the carbon tax revenue is recycled. It is progressive for the case of uniform lump-sum transfers. Nationwide, its overall net impact is progressive for all scenarios, as can be seen from the reduction in the Gini coefficients. In general, the finding in this paper confirms other literature from developing countries about the progressivity of the impact of a carbon tax.

Table 4 Distributional effect of carbon tax policies

	SIM1 No-revenue recycling	SIM2 Uniform cut on com. tax rate	SIM 3 Uniform transfers
Urban			
Ex-ante poverty incidence (%)	13.6	13.6	13.6
Ex-post poverty incidence (%)	13.77	13.61	12.92
Change in poverty incidence (%)	0.17	0.01	−0.68
Rural			
Ex-ante poverty incidence (%)	20.2	20.2	20.2
Ex-post poverty incidence (%)	19.43	19.74	16.2
Change in poverty incidence (%)	−0.77	−0.46	−4
Urban + rural			
Ex-ante poverty incidence (%)	17.19	17.19	17.19
Ex-post poverty incidence (%)	16.85	16.95	14.7
Change in poverty incidence (%)	−0.34	−0.24	−2.49
Urban			
Ex-ante Gini coefficient	0.35	0.35	0.35
Ex-post Gini coefficient	0.35	0.35	0.34
Change in Gini coefficient	–	–	−0.01
Rural			
Ex-ante Gini coefficient	0.28	0.28	0.28
Ex-post Gini coefficient	0.27	0.28	0.26
Change in Gini coefficient	−0.01	–	−0.02
Urban + rural			
Ex-ante Gini coefficient	0.35	0.35	0.35
Ex-post Gini coefficient	0.35	0.35	0.33
Change in Gini coefficient	–	–	−0.02

com. tax rate commodity tax rate, – trivial

4.3 Revenue-cycle

Comparing alternative revenue-recycling mechanisms, it suggests that a uniform reduction in the general commodity tax rate (SIM 2) has a favourable aggregate welfare impact (in terms of aggregate real consumption and GDP) (Table 1). However, in terms of equity objectives, uniform lump-sum transfers (SIM 3) produce a much more favourable distributional impact. Inequality nationwide falls the most. Gini coefficients fall by more than they do with the uniform sales tax cut. The poverty impact of uniform lump-sum transfers is also most favourable where poverty nationwide falls by 2.5 %, which is contributed mostly by the fall in rural poverty incidence by 4 % (Table 4).

The choice between implementing sales tax cuts and lump-sum transfers hence depends on which one the government considers to have greater priority and the political visibility in implementing one or the other. Another possibility is conducting both policies at the same time.

5 Conclusions

Using Indonesia as the case study and a CGE with hundreds of household groups as the methodology, this paper attempts to analyse the distributional impact of a carbon tax implemented on energy sources such as coal, gasoline, automotive diesel oil, kerosene and natural gas.

As the fourth largest country in terms of population, a slight change in its emissions per capita will most likely significantly change the global emission level, so that Indonesia's stance has a significant bearing on global climate change policy. Among developing countries, Indonesia ranks 7th in total CO_2 emission from fossil fuel and ranks 2nd, after China, if CO_2 emission from land use change is included. Indonesia's ability to control emissions is therefore of great global concern.

This paper also tries to demonstrate that disaggregating households by centile of expenditure per capita (made possible by constructing a highly disaggregated Social Accounting Matrix), fully-integrated into a CGE model, not only allows simultaneous consideration of both income and expenditure patterns as inseparable driving forces in income distribution in an economy-wide framework, but also allows for more direct and accurate calculation of inequality indicators and poverty incidences.

Parameters utilised in this paper are taken from the GTAP database and an Indonesia CGE model developed by Monash University and the Indonesian Ministry of Energy—relatively reliable sources used in many previous studies.[8]

Analysing the carbon abatement policy via the introduction of a carbon tax in Indonesia, the results from various simulations suggest that in contrast to most studies from developed countries, the distributive effect of a carbon tax in Indonesia is not necessarily regressive. It is strongly progressive, and robust compared to various alternative recycling-schemes in rural areas; and either neutral or slightly progressive in urban areas. Its overall distributive effect nation-wide is progressive. This conclusion, in general, confirms other literature from developing countries about the progressivity of the impact of a carbon tax.[9]

A closer look at what may contribute to the favourable distributive effect of the carbon tax reveals that the progressivity is driven by both the income and the expenditure patterns of households. The resource reallocation in the economy due to the introduction of a carbon tax is in favour of factors endowed more proportionally by rural, and lower income class households, as shown, for example, by the contraction of the energy intensive manufacturing sectors and the expansion of agricultural and service sectors. The typical expenditure pattern in developing

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[8] A sensitive analysis presented in Appendix 1 shows that results of simulations conducted in this paper are relatively robust.

[9] Alternative scenarios presented in Appendix 2 show that the conclusions in this paper are relatively robust.

countries, which is less energy-sensitive, also helps drive the progressivity of the result, especially in rural areas.

The other major issue for developing countries before deciding to fully participate in global efforts to mitigate climate change is what the impact will be of mitigation policies in the non-fossil fuel sectors, such as in forestry and agricultural sectors. As mentioned in the introduction of this paper, for a large country such as Indonesia, the main source of carbon emission is deforestation and land use changes. Future researchers should work on this area.

Appendix 1: Sensitivity analysis

In a CGE exercise, because some of the parameters are taken from other sources such as others studies, models, or literature, it is necessary to examine the reliability of the results with respect to uncertainty in the parameters. In a standard or 'ad-hoc' sensitivity analysis, the model is solved for one or two different sets of parameters, and then the sensitivity of the change in endogenous variables is examined. However, since there are many parameters inputted into the model, this approach is difficult or less practical to implement when we want to examine the sensitivity of the results on the independent uncertainty about the values of several parameters. In this model, for example, for Armington elasticity alone, because the model has 38 different commodities, a sensitivity analysis on each of the parameters would be computationally burdensome. This paper hence chooses the systematic sensitivity analysis (SSA) via the Gaussian Quadrature method to conduct a sensitivity analysis (Arndt 1996; Pearson and Arndt 2000). Given the distribution of M parameters, this method deals with finding the best possible choice of parameters in N simulations if we want to estimate means and standard deviations for all endogenous variables. Arndt (1996) has shown that the results using this method are surprisingly accurate, given the relatively modest number of times the model is solved.

Table 5 shows the result of systematic sensitivity analysis for carbon tax simulation (SIM 1, no-recycled revenue), assuming triangular distribution for all parameters and allowing each of the parameters to vary by as much as 50 % from its mean. In general, though some variables tend to be more sensitive than others, Table 5 suggests that the result of carbon tax simulation is robust to variation in the extraneous parameters as shown by low standard deviation of most endogenous variables.

Looking at the confidence interval in real household expenditure by centiles also suggests that the distributional impact of a carbon tax is less likely to be sensitive to parameter variation. For example, it can be seen that with a 95 % confidence level, the real expenditure of the poorest (the centile 1st household group) group will rise by not less than 1.342 % and that of the richest (the centile 100th household group) will not increase (0 % rise in expenditure per capita). Therefore, the carbon tax tends to reduce inequality in rural areas.

An idea of the direction of the poverty impact can also be obtained by looking at what happens to households close to the poverty line. In urban areas, for example, it

Table 5 SSA of SIM 1: carbon tax (50 % variation in all parameters) (in %age change)

	Mean	s.d.	Con. interval (95 %)	
			Lower	Upper
Macroeconomics				
GDP	−0.040	0.013	−0.098	0.018
Aggregate consumption	−0.061	0.020	−0.148	0.027
CPI	1.324	0.033	1.174	1.473
CO_2 emission	−6.535	0.656	−9.468	−3.602
Real wage				
Agriculture, rural, formal	−0.587	0.127	−1.154	−0.021
Agriculture, urban, formal	−0.548	0.118	−1.077	−0.020
Agriculture, rural, informal	−0.478	0.120	−1.015	0.059
Agriculture, urban, informal	−0.497	0.111	−0.995	0.002
Production, rural, formal	−2.691	0.178	−3.487	−1.894
Production, urban, formal	−4.647	0.190	−5.497	−3.798
Production, rural, informal	−2.236	0.195	−3.106	−1.365
Production, urban, informal	−2.245	0.202	−3.148	−1.342
Clerical, rural, formal	−2.178	0.069	−2.487	−1.869
Clerical, urban, formal	−3.126	0.111	−3.625	−2.628
Clerical, rural, informal	−1.763	0.114	−2.274	−1.253
Clerical, urban, informal	−1.786	0.112	−2.285	−1.287
Professional, rural, formal	−3.183	0.134	−3.781	−2.586
Professional, urban, formal	−3.551	0.115	−4.065	−3.037
Professional, rural, informal	−2.198	0.184	−3.021	−1.375
Professional, urban, informal	−2.070	0.114	−2.581	−1.558
Average price of capital	−4.447	0.082	−4.813	−4.082
Average price of land	0.919	0.116	0.401	1.436
Output				
Coal	−2.933	0.454	−4.965	−0.901
Natural gas	−0.687	0.139	−1.310	−0.064
Refinery	−3.837	0.447	−5.838	−1.837
Electricity	−1.436	0.090	−1.841	−1.032
Water and gas	−2.238	0.066	−2.535	−1.941
Road transportation	−0.663	0.077	−1.007	−0.318
Other transportation	−1.430	0.172	−2.200	−0.659
Prices				
Coal	131.877	1.574	124.840	138.914
Natural gas	26.561	1.542	19.663	33.459
Gasoline	24.626	0.294	23.311	25.940
Diesel (automotive)	45.251	0.828	41.550	48.952
Diesel (industries)	43.442	0.786	39.928	46.956
Kerosene	29.305	0.534	26.915	31.695
LPG	25.714	1.293	19.932	31.495

Table 5 continued

	Mean	s.d.	Con. interval (95 %)	
			Lower	Upper
Other fuels	21.389	0.696	18.275	24.503
Electricity	16.953	0.852	13.144	20.761
Water and gas	12.379	0.295	11.058	13.699
Road transportation	1.763	0.060	1.493	2.032
Other transportation	2.349	0.072	2.027	2.672
Real consumption				
Urban				
Centile 1	0.135	0.031	−0.005	0.275
Centile 2	0.083	0.031	−0.054	0.220
Centile 3	0.060	0.030	−0.072	0.193
Centile 4	−0.306	0.031	−0.443	−0.168
Centile 5	−0.514	0.039	−0.687	−0.342
Centile 13	−0.296	0.029	−0.423	−0.168
Centile 95	−0.247	0.028	−0.372	−0.123
Centile 96	−0.407	0.024	−0.513	−0.302
Centile 97	−0.223	0.026	−0.339	−0.107
Centile 98	−0.569	0.022	−0.669	−0.470
Centile 99	−0.509	0.020	−0.597	−0.421
Centile 100	−0.343	0.026	−0.458	−0.229
Rural				
Centile 1	1.657	0.070	1.342	1.972
Centile 2	1.546	0.068	1.242	1.849
Centile 3	1.625	0.077	1.280	1.970
Centile 4	1.711	0.063	1.428	1.994
Centile 5	1.453	0.063	1.171	1.735
Centile 20	1.157	0.058	0.899	1.415
Centile 95	0.002	0.040	−0.176	0.179
Centile 96	−0.228	0.038	−0.396	−0.059
Centile 97	−0.251	0.035	−0.408	−0.093
Centile 98	−0.123	0.040	−0.302	0.056
Centile 99	−0.049	0.049	−0.267	0.169
Centile 100	−0.224	0.050	−0.448	0.000

is the 13th centile household group. Since its 95 % confidence interval is between −0.386 and −0.205, with 95 % confidence it can be concluded that poverty in urban area falls following the introduction of a carbon tax.

The same robustness is also expected for the other simulations conducted in this paper.

Table 6 Impact of carbon tax policies on industrial outputs (in %age change)

	SIM 1A No-revenue recycling	SIM 2A Uniform cut on com. tax rate	SIM 3A Uniform transfers
Paddy	0.08	0.09	0.26
Other food crops	0.04	−0.08	0.08
Estate crops	−0.12	−0.08	−0.35
Livestock	0.12	0.13	0.32
Wood and forests	0.08	0.14	0.04
Fish	−0.07	−0.03	−0.02
Coal	−2.61	−2.65	−2.65
Crude oil	−0.26	−0.28	−0.25
Natural gas	−0.62	−0.64	−0.62
Other mining	−0.09	−0.22	−0.07
Rice	0.09	0.09	0.28
Other food (manufactured)	0.14	0.17	0.53
Clothing	0.37	0.89	0.58
Wood products	0.20	0.30	0.03
Pulp and paper	−0.07	0.16	−0.13
Chemical product	−0.59	−0.25	−0.38
Petroleum refinery	−3.49	−3.72	−3.43
LNG	−2.54	−2.58	−2.56
Rubber and products	−0.19	0.50	−0.47
Plastic and products	−0.04	0.43	0.06
Nonferrous metal	−1.45	−1.79	−1.35
Other metal	−0.33	−0.11	−0.25
Machineries	−0.46	2.27	−0.22
Automotive industries	0.32	−0.07	−0.42
Other manufacturing	0.18	0.35	0.68
Electricity	−1.30	−1.23	−1.18
Water and gas	−2.02	−1.98	−2.45
Construction	−0.01	−0.01	−0.02
Trade	0.04	0.09	0.26
Hotel and restaurants	0.27	0.10	0.22
Road transportation	−0.59	−0.61	−0.52
Other transportation	−1.28	−1.18	−1.30
Banking and Finance	0.21	0.02	0.09
General government	0.00	0.00	0.00
Education	0.10	0.06	0.04
Health	0.28	0.16	0.45
Entertainment	0.54	0.45	0.20
Other services	0.26	0.04	−0.23

com. tax rate commodity tax rate, *LNG* liquefied natural gas, – trivial

Table 7 Distributional effect of carbon tax policies

	SIM1A No-revenue recycling	SIM2A Uniform cut on com. tax rate	SIM 3A Uniform transfers
Urban			
Ex-ante poverty incidence (%)	13.6	13.6	13.6
Ex-post poverty incidence (%)	13.73	13.6	12.95
Change in poverty incidence (%)	0.13	–	−0.65
Rural			
Ex-ante poverty incidence (%)	20.2	20.2	20.2
Ex-post poverty incidence (%)	19.49	19.76	16.51
Change in poverty incidence (%)	−0.71	−0.44	−3.69
Urban + rural			
Ex-ante poverty incidence (%)	17.19	17.19	17.19
Ex-post poverty incidence (%)	16.87	16.95	14.89
Change in poverty incidence (%)	−0.33	−0.24	−2.30
Urban			
Ex-ante Gini coefficient	0.35	0.35	0.35
Ex-post Gini coefficient	0.35	0.35	0.34
Change in Gini coefficient	–	–	−0.01
Rural			
Ex-ante Gini coefficient	0.28	0.28	0.28
Ex-post Gini coefficient	0.27	0.27	0.26
Change in Gini coefficient	−0.01	−0.01	−0.02
Urban + rural			
Ex-ante Gini coefficient	0.35	0.35	0.35
Ex-post Gini coefficient	0.35	0.35	0.33
Change in Gini coefficient	–	–	−0.02

com. tax rate commodity tax rate, – trivial

Appendix 2: Alternative scenario

This section provides alternative scenarios in which the three scenarios are implemented with a similar carbon reduction target; i.e., a reduction of 6 % from the initial condition. In other words, in the first scenario (SIM 1A), a carbon tax is implemented, in such that the total reduction of carbon is as much as 6 % less than the initial level, without revenue recycling. In the second scenario (SIM 2A), the implementation of the carbon tax will be accompanied by a reduction in a uniform general ad-valorem sales tax rate for all commodities, such that extra government revenue disappears, while controlling the total reduction of carbon is at exactly the same level as that of the first scenario (SIM 1A). In the third scenario (SIM 3A), the implementation of the carbon tax will be accompanied by making a uniform lump-sum transfer to all households. The total reduction of carbon in this scenario (SIM 3A) is controlled to be similar to that of the first scenario (SIM 1A). The results can be seen in Tables 6 and 7. These alternative scenarios do not change either the contents of the discussion or the conclusion of this paper.

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