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On the Distributional Effect of Carbon Tax in Developing Countries: The Case of Indonesia[1]

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This paper analyses the distributional impact of carbon tax in Indonesia, one of the largest carbon emitter developing countries. Using a Computable General Equilibrium (CGE) model with disaggregated households, the result suggests that in contrast to most studies from industrialised countries, the introduction of carbon tax in Indonesia is not necessarily regressive. Its structural change and resource reallocation effect, following the carbon tax, is in favor of factors endowed more proportionately by rural, and lower income households. In addition, the expenditure of lower income households, especially in rural area, are less sensitive to the prices of energy-related commodities. Revenue-recycling through uniform reduction in commodity tax rate may reduce the adverse aggregate output effect, whereas uniform lumpsum transfers may enhance the progressivity. This study demonstrates an example, that encouraging developing countries to reduce carbon emission, may not only increase the efficiency of carbon abatement globally, but also have desirable distributional implication in the developing countries themselves.

Key Words: Carbon Tax, Climate Change, Distribution, CGE, Indonesia
JEL Classification: D30; D58; Q40; Q48; Q54; Q56; Q58

1. BACKGROUND

The problem of global warming has increasingly become more alarming, and scientific studies are now more conclusive that humans are responsible[3]. In a famous report, Stern (2006) suggests scientists are now able to attach probabilities to temperature outcomes and impacts on the natural environment associated with different levels of greenhouse gas stabilisation. For example, his report suggests that without appropriate action, there is at least a 50% chance of exceeding a 5^0C global average temperature change during the following decades. Such a change would transform the physical geography of the world.

Despite these concerns, multilateral action for greenhouse gas stabilisation, such as proposed under the Kyoto Protocol, have been less than promising. One of the main reasons for this is the associated high cost of such action in terms of economic growth. This argument has been used by both the U.S. and Australian governments against ratifying the Kyoto Protocol and is a clear example of the perception or belief that economic and environmental objectives cannot go hand in hand.

The linkage between the economic, environmental and social dimensions of sustainable development was first introduced in the 1987 Bruntland report. It was again emphasised in the 2002 Johannesburg World Summit as being the three pillars of sustainable development and by this time the environmental

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[3] As reported by the recent fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC), published in February, 2007 (source: The Economist, February 8^{th} 2007, 'Climate change: Heating Up'.)

link included climate change. With the issue of climate change, the inter-related elements of sustainable development could be in conflict.

Equity is an integrated part of global climate change policy. This includes how the responsibility of actions should be distributed 'fairly' across nations. This was the reason why the 1992 United Nations Framework Convention of Climate Change (UNFCC) declared that the responsibility of actions across nations should follow the principle of 'common but differentiated responsibilities'. Sharing the burden equally is regarded as unfair owing to developing countries' historically low greenhouse gas emissions. However, the lack of a formal commitment for developing countries under the Kyoto Protocol has been used as by the U.S. as an argument against ratification.

Participation by developing countries in stabilising global greenhouse gas emissions is crucial and would be the important driver needed to resume the halting progress of multilateral efforts. Per capita carbon emissions in developing countries are still much lower than that of developed countries. Nevertheless, developing countries are increasingly contributing to the accumulation of greenhouse gases. Developing countries already account for half of annual global greenhouse gas emissions, and future emission growth will mainly come from developing countries (Jotzo, 2004).

For the developing countries themselves, there are many reasons to justify more active participation in global carbon stabilisation. The impact of climate change tends to hurt the poorest countries most, and this includes Indonesia. Developing regions are already warmer, suffer from high rainfall variability, are heavily dependent on agriculture, and suffer from a lack of adequate health provision and low-quality public services. Being low income countries with low budget constraint, adaptation to harmful effects of climate change will be more difficult (Stern, 2006).

As the fourth largest country in terms of population, Indonesia is important in global climate change policy. Even though it ranks 7^{th} in total CO_2 emission from fossil fuels among developing countries, Indonesia ranked 2^{nd}, after China in 2000 if CO_2 emissions from land use change (mainly deforestation) are included[4]. In fact, even including industrialised countries, Indonesia is one of the 20 biggest carbon emitting nations overall in 2002, with emissions continues to grow rapidly at around 6.6% annually.

The changing composition of Indonesia's energy mix has also caused some concern about the Indonesian contribution to the global climate problem. Although emissions from consumption of liquid petroleum products is still dominant (amounting to 49% of Indonesia's 2002 fossil-fuel CO_2 emissions), emissions from natural gas consumption and coal usage, although quite variable, have risen steadily since the early 1970s and accounted for 15% and 24% of Indonesia's total 2002 emissions. As Indonesia is running out of oil, the future priority of coal as an alternative fuel for electric power generation has become an important item on Indonesia's future agenda. Indonesia recently became a net oil importer, and its coal reserves with current production capacity will last for the next 50 years (Tanujaya, 2005). In addition, with a population exceeding 210 million people, although Indonesia's per capita emission rate of 0.39 metric tons of carbon in 2002 is well below the global average, it has grown ten-fold since the early 1950s (Marland et al., 2005).[5]

Although discussion on the formal commitment of carbon emission stabilisation in developing countries, as well as in Indonesia, is perhaps still in its infancy, it has recently gained a lot more attention, even in Indonesia itself. Indonesia recently ratified the Kyoto Protocol[6]. One of the obligations as a party to the convention is to communicate actions taken to mitigate climate change and also to establish a National Committee on Climate Change. By ratifying the protocol, the issue of reducing greenhouse gas emissions will have more prominence in public discourse.

Carbon abatement policy, like many other environmentally-motivated policies, carries a distributional

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[4] Source: World Resource Institute Online Database.

[5] See figure 1.

[6] In July 2004 (Jotzo, 2004).

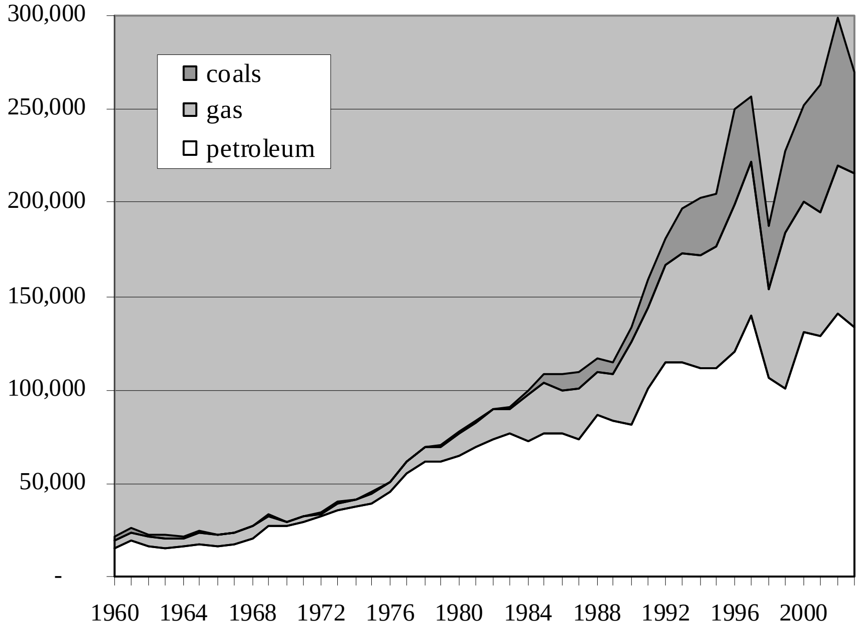

FIG. 1 Trend of Indonesian CO_2 emission by sources 1960 − 2003 (thousand tonnes)

effect within a country that implements it. A complete picture of this distributional impact has to consider two distinct but inseparable issues (OECD, 1994). The first is the concerns related to the distribution of the environmental benefit of the policy, who gains more and who gains less. The second concern is associated with distribution of the financial effects of the policies, who pays more and who pays less.

In relation to potential distributional benefits from a global reduction in greenhouse gas emissions, in the case of Indonesia, the questions to be asked are, among others, which parts and/or sectors of the country and its population are likely to be affected. On the other hand, the distribution of financial effects relates more to how the costs of compliance or implementation of policy will be distributed across different groups. The implementation costs of environmental policies can be socially regressive. Lower-income groups may be subject to a disproportionately higher share of environmental compliance costs. The case study in this chapter is intended to address this part of the distributional story.

The conflict between environment and equity objectives in the case of carbon abatement policies has been prevalent, as the literature from developed countries has suggested. A carbon tax has been mostly found to be regressive, that is, lower income households pay disproportionately more than higher income households.

As discussed previously, the increasing relevance of developing countries' role in global climate change policy is one of the motivations for this case study. However, this chapter is also motivated by the empirical regularities from developed country studies that carbon abatement policies are regressive. In short, this research is mainly motivated by the lack of emphasis in the literature on the distributional aspect of carbon abatement policy in developing countries.

There are many possible developing-countries' characteristics that may point to a conclusion that environmental policies such as a carbon abatement policy may not necessarily be regressive in developing countries. In Indonesia, as in some other developing countries, although the manufacturing sectors, is relatively more energy-intensive, its share has increasingly been more dominant in the economy's output, yet the largest share of the labour forces is still employed in the agricultural sector and to some extent the services sector. A carbon abatement policy will most likely hit energy-intensive sectors which are typically also capital intensive. The returns to factors that are more intensively employed in these sectors, such as capital, skilled-labour, and formal urban workers, will be under more pressure than factors more intensively employed in less energy intensive sectors,such as agriculture and some of the services sector. These are, among others, land, informal urban, and rural agricultural workers. As the owners of factors in the less energy intensive sectors are most likely to be lower income households, this may drive the distributional impact of a carbon abatement policy to be more progressive than regressive.

Moreover, in contrast to developed countries, the expenditure pattern of lower income households in developing countries is likely to be less energy-intensive. For example, in countries like Indonesia, domestic heating is not part of everyday consumption, vehicle ownership is still a luxury for the majority of the population, and electricity consumption, including its use for energy-intensive household appliances, is still not regarded as a necessity, especially in rural areas, where most Indonesians live.

Encouraging developing countries to participate more actively in the global multilateral effort for greenhouse gas stabilisation has increasingly become necessary. If these typical characteristics of developing countries do drive the distributive effect of a carbon abatement policy to be more progressive, it may have important policy implications at both the local and global level. At the local level, if its known to be non-regressive, the effort to curb greenhouse gas emission will generate less political and social resistance. At the global level, understanding that carbon abatement policies may not necessarily carry adverse distributional effects in developing countries, may add more social benefit, in terms of distributional implication, when the location of carbon abatement is partially shifted from developed to developing countries.

2. EMPIRICAL REGULARITIES IN THE DISTRIBUTIVE EFFECT OF CARBON ABATEMENT POLICIES

2.1. Empirical Findings from Industrialised Countries

Most of the studies reviewed in this paper are from developed countries. Environmental problems could be considered new issues in development as they only started to gain widespread global attention in the 1970s, especially after the Stockholm Conference on the Human Environment in 1972. It is therefore understandable that the distributional aspect of environmental policy in developing countries has not become a focus of attention. For the case of a carbon tax Baranzini et al. (2000, p. 405), for example, confirm that there are few studies on the distributional effects of a carbon tax in developing countries or countries with economies in transition. The lack of studies from developing countries widens the relevance of the research in this thesis.

A study on American households by Poterba (1991) is considered to be one of the earliest study. He analyses the distributional effect of a carbon tax by examining the expenditure pattern of households, especially the pattern of energy spending. The policy he examines is a charge of US$100 per ton of carbon implemented in 1990. Using data from the U.S. Consumer's Expenditure Survey, Poterba (1991) assumes that the US$100/ton carbon tax is fully translated into the purchaser's price[7] of various energy related products, and combines these with the data on energy expenditure pattern to estimate the distributional burden of the carbon tax. He concludes that a carbon tax is regressive which suggest that if a carbon tax were adopted without any offsetting changes in other tax or transfer programs, the burden would fall more heavily on low-income than well-off households.

The source of the regressivity is apparently that the share of income low-income households devote

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[7] Producer's price is not affected.

to heating fuel, electricity, and gasoline is significantly higher than that of better-off households. In other words, that energy-related commodity was in fact a necessity for American households. Poterba (1991, p. 8), for example reports that total energy outlays for households at the 25th percentile of the income distribution are approximately 16% of income, compared with only 7% for households at the 75th percentile of the distribution.

Another early work is by Pearson and Smith (1991) using a more or less similar method to Poterba (1991). This study examines the distributive effect of a carbon tax in European countries. For the U.K., the study uses the 1988 UK Family Expenditure Survey, and examines the impact of a tax on carbon and energy at a level equivalent to US$10 per barrel. For U.K. households, the result suggests the poorest quintile would pay 2.4% of their spending, while, the richest quintile would pay only 0.8%. Pearson and Smith (1991, p. 42) conclude that in nominal terms, the carbon tax payments are slightly lower, but show broadly similar effects: higher tax payments amongst the rich than the poor, but the burden of the tax in relation to household spending being higher for the poor than for the rich.

However, using a similar calculation for six other European countries, Pearson and Smith (1991) suggest that the burden of carbon tax payments is only weakly related to income or mildly regressive, except in Ireland where it tends to be strongly regressive. In their review Barker and Köhler (1998) support this finding and suggest that "carbon and energy taxes were weakly regressive for most countries, but more strongly regressive for the UK and Ireland" (p. 377).

A study for Canada was conducted by Hamilton and Cameron (1994), estimating the distributional impact of meeting the Rio target of stabilising CO_2 emissions at the 1990 level by the year 2000. The methodology used is a combination of three different methods. To get the estimated level of carbon tax to meet the stabilisation target, Hamilton and Cameron (1994), use a Computable General Equilibrium (CGE) model of the Canadian Department of Finance. The model suggests a carbon tax of US$101.56 per tonne. Using an Input-Output model, this carbon tax is then translated into increases in all prices in the economy. These price increases are then used in a micro-simulation model using Statistics Canada's micro-simulation model. The result suggest that the distributional consequences of the simulated tax are moderately regressive: decrease in consumable income for the lowest quintile of households are from 1.1 to 1.2 percent larger than for the highest quintile (Hamilton and Cameron, 1994, p. 394).

Cornwell and Creedy (1996) investigate the distributional implication of a reduction in emissions of 20% per cent of 1988 levels by 2005 to meet the Toronto target for Australia. The methodology used is a combination of Input-Output analysis and household demand system, which they describe as a three-stage process. In the first stage, the carbon tax is shifted forward to consumers, increasing the price of goods in proportion to their carbon content. The second stage is calculating the demand response of consumers to the price changes. In this stage, Australian Household Survey (HES) data is used to calculate elasticities of demand for various income groups. The third stage, is to calculate the new levels of aggregated demand to determine the amount of emission reductions.

The result suggests that a carbon tax of AU$113 per tonne of CO_2 is needed to reduce emissions by 20 per cent. With regard to distributional results, the general conclusion suggests the distributive effect is regressive. For example, the simulation, increases the Gini coefficient from 0.2778 to 0.2838.[8]

Barker and Köhler (1998) examine the distributional effect of imposing additional excise duties on energy products according to their carbon content. The countries they analyse are quite comprehensive comprising all members of the European Union. The methodology used in this study is called the energy-environment-economy model for Europe (E3ME), a sectoral, regionalised, econometric model. Barker and Köhler (1998) argue that the model treats member states as distinct economic entities interacting with one another but the same time it is still one model. The model includes 11 member states, 30

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[8] Table 3 of Cornwell and Creedy (1996, p. 31)

industries, 27 consumer categories, 17 fuel users and 11 fuels with detail on CO_2 emissions.

The policy scenario is an increase in excise duties on energy products, such that it escalates from 1999 to 2010 and achieves levels reducing CO_2 emissions by 10 per cent below the baseline by 2010 for 11 EU member states. The results without revenue recycling suggest the excise duties are regressive, but progressive if revenue from the additional excise duties is recycled as lump-sum transfers. For example Barker and Köhler (1998, p. 399) conclude that "the package of measures that is examined here is regressive across expenditure groups ...." It is also suggested that the results are dominated by the effects of domestic energy taxes, which are weakly regressive.

Labandeira and Labeaga (1999) study the impact of a tax levied on Spanish energy-related CO_2 emissions. A two stages approach is used in the study. The first step uses an Input-Output demand model to calculate the price effects of the Spanish carbon tax. The price effect is then transmitted into the second stage, using a micro-simulation model of an estimated consumer's demand system (Almost Ideal Demand System) which yields consumer reaction to the carbon tax as well as its distributional outcomes.

The policy examined is a hypothetical carbon tax rate with a rate chosen to reflect the damage associated with Spanish CO_2 emissions. Using a damage estimate from the literature, Labandeira and Labeaga (1999) focus on the impact of a carbon tax of US$20.3 per tonne of carbon. In contrast with other studies, Labandeira and Labeaga (1999) do not find that a carbon tax in Spain is regressive and concludes that the variation of equivalent losses across total expenditure deciles is inconclusive on the regressivity of the reform, although the reform has a greater effect on households with older heads (Labandeira and Labeaga, 1999, p. 318).

Symons et al. (2000) examine the likely immediate impact of a pollution tax on the tax burden of households in a number of European countries. Although a number of pollutants are examined, they focus on CO_2. The method is basically similar to many other studies, such as Labandeira and Labeaga (1999) and Cornwell and Creedy (1996), where an input-output framework is used to assess the likely impact of pollution/energy taxes, via increases in the cost of using fossil fuels, upon the prices of consumer goods. The Input-Output approach is then combined with investigation of the expenditure patterns of households, where the price changes deriving from the taxes are linked to consumer demand.

The policy scenarios used in the study are a CO_2 tax of 0.1ECU per kg emissions of CO_2 and an energy tax that raises the same revenues as the CO_2 tax. Revenue recycling is not included in the analysis because of the need to know the extent of the regressivity of the tax without any additional effects (Symons et al., 2000, p. 7).

The results suggest that both a CO_2 tax and energy tax are regressive in Germany, where for CO_2, the lowest income groups pay 8% of expenditure, while the highest income group pay just above 5%. The tax is also regressive for France and slightly regressive for Spain. The result for Spain is slightly different to the study by Labandeira and Labeaga (1999), where they found neutrality of a carbon tax. However, in Italy, the result is neutral, and in contrast to other studies, is progressive for the U.K.

Tiezzi (2001) simulate the welfare effects of the carbon-energy tax implemented in Italy in 1999. The methodology used is the True Cost of Living index number[9] for which the parameters have been obtained through demand system estimation using household level data from 1985 to 1996.

The policy examined is a new green tax, which is a carbon-energy tax based on a reduction in CO_2 emissions. The policy is in line with the national actions defined in 1988 to reduce CO_2 emissions in order to comply with the obligations of the Kyoto Protocol (Tiezzi, 2001, p. 3). It is concluded that contrary to what has been found in other similar studies, the tax burden is proportionally distributed

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[9] Tiezzi (2001, p. 5) describes a true cost-of-living index number (TCOL) as comparing the cost of achieving a given level of economic welfare before a price increase with the cost of achieving the same level of economic welfare after the price increase and measures how much extra income is needed to get back to the original welfare level.

across households at different welfare levels. Thus the presumed regressivity of carbon taxation is not sustained in Italy. Tiezzi (2001, p. 12) suggests that this might be due to the fact that reform has mainly hit transport fuels, whereas heating fuels price have increased relatively less.

Jacobsen et al. (2003) analyses the distributional implications of environmental taxation in Denmark. The taxes examined in the paper are various individual taxes, as well as the combination of all these taxes and duties related to environmental concerns. The method used by Jacobsen et al. (2003) is an examination of survey data of 3.3 per cent of the Danish population. The distributional impact is examined by looking at tax payments relative to disposable income for each income decile. Comparing the pattern of tax payments, Jacobsen et al. (2003, p. 495) concludes that the distributional effect varies a great deal between different environmental taxes, with transport-related taxes reducing after-tax inequality, and green taxes including CO_2 tax increasing inequality".

Brannlund and Nordstrom (2004) analyse consumer responses to changes in energy or environmental policy in Sweden. Sweden introduced a CO_2 tax in 1991, initially set at the level of US$30 per tonne. As at January 1, 1997 the tax rose to US$46 per tonne and green policy has become the Swedish policy agenda ever since.

The methodology used by Brannlund and Nordstrom (2004) is an econometric model for non-durable consumer demand that utilises micro and macro-data. They estimated a system of demand equations using micro-data from Swedish Household Expenditure Surveys with aggregate data from the Swedish National Accounts. The distinguished feature of this micro-simulation model is the incorporation of a labour-leisure choice. The specification of the demand system is the quadratic Almost Ideal Demand System or QAIDS.

The policy simulation is intended to illustrate the response and distributional impact of non-marginal changes of the CO_2 tax. The motivation is the Swedish commitment according to the Kyoto-protocol. Two scenarios are considered. The first is a 100% increase in the CO_2 tax with a tax replacement of a lower general VAT, and the second scenario is the same CO_2 tax but with a tax replacement in the form of lower VAT on public transport.

It appears the distributional impact of the first simulation is regressive. Households with the lowest income quintile pay 0.52 per cent of their disposable income, and households with the highest income quintile pay only 0.33 per cent. Brannlund and Nordstrom (2004, p. 225), conclude that the welfare effect differs substantially between household categories and relative to disposable income the welfare loss will be greater for low income household indicating that the tax is regressive.

With regard to the second simulation, the result also suggests regressivity. Households with the lowest income quintile experience a welfare loss of 0.46 per cent of their disposable income, while households with the highest income quintile only experience 0.4 per cent. Brannlund and Nordstrom (2004, p. 227) conclude that compared with the first scenario, the welfare loss relative to disposable income is distributed in a similar manner.

Wier et al. (2005) examine whether a carbon tax is regressive in Denmark. This policy is very important in Denmark because it was one of the first countries to impose explicit CO_2 taxes on both household and business energy consumption in 1992/1993. Denmark carries one of the heaviest environmental tax burdens in the world, bringing in around 10% of public revenues.

The methodology used by Wier et al. (2005) is the combination of Input-Output model and household survey data which is common in the literature[10]. The Input-Output model is used to calculate actual indirect tax payments by households for different types of commodities, whereas the consumer survey from Statistics Denmark is used for distributional analysis.

The results suggests that the carbon tax payment in Denmark is regressive. Wier et al. (2005, p.

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[10] The same method is used, for example, by Symons et al. (2000), Labandeira and Labeaga (1999) and Cornwell and Creedy (1996).

244), for example, report that as income rises, a falling share going to environmental taxes indicates a regressive tax. They suggest more explicitly that low-income families paid (direct as well as indirect) CO_2 taxes constituting around 0.8% of disposable income, while high-income families paid CO_2 taxes constituting around 0.3% of disposable income (Wier et al., 2005, p. 245). However, Wier et al. (2005) suggest the degree of regressivity of CO_2 taxes decreases when using total expenditure instead of income.

To summarise, although not all studies reviewed conclude regressivity of environmental policy related to energy and carbon emissions, the literature generally suggests environmental policy in the form of a carbon tax or energy tax is regressive. The burden is borne proportionately more by lower income households. Similar conclusions are shared by other studies that survey more or less similar literature. The survey by Baranzini et al. (2000), OECD (1994), OECD (1996), Kristörm (2003), and Boyce et al. (2005) confirm this general tendency.

In its report, specific for carbon tax, OECD (1995, p. 57) concludes:

> "With regard to income distributional effects, empirical studies suggest that a national carbon tax or trading programme would be at least mildly regressive (i.e., would impose greater percentage burdens on the lower income groups) in many OECD countries, although there is some evidence that such programmes might actually be progressive in developing countries."

With regard to environmental policy related to energy, a study by OECD (1996) also reaches more or less similar conclusions. They suggest "in some OECD countries, domestic energy has the character of a necessity in household budgets, and taxes on domestic energy are correspondingly regressive (OECD, 1996, p. 61)."

Baranzini et al. (2000), in their evaluation of carbon taxes with regard to their competitiveness, distributional and environmental impact, suggest a tendency toward regressivity. They conclude:

> "Results from empirical studies show that carbon taxes are generally regressive, ... For instance, of the seven studies reviewed by [the 2nd Assessment Report of the IPCC] four indicate that carbon taxes are regressive, while others indicate possible proportional or progressive impacts (Baranzini et al., 2000, p.404)."

Boyce et al. (2005, p. 3), after reviewing studies on distributional impact of carbon tax in developed countries, also conclude:

> "Studies in [European] and other industrialised countries generally have concluded that carbon charges are regressive – taking a bigger slice in percentage term from low-income households than from high-income households – or in some case distributionally neutral or mixed."

In other words, the literature from developed countries suggests environmental policies (in the form of energy-related policies, or climate change policy) tend to be regressive.

2.2. Developing Countries Studies

As suggested earlier, compared to numerous studies from industrialised countries, studies from developing countries analysing the distributive effect of environmental policies hardly exist. Among the few are an early study by Shah and Larsen (1992), and recent studies by Corong (2007) and Boyce et al. (2005).

Concerning the case that most of the studies are from developed countries, Shah and Larsen (1992) argue that the conclusion from the developed country literature which confirms the regressivity of environmental policies, particularly carbon taxes, may not necessarily apply to developing countries. They argue that the source of the regressivity may have been a declining share of fossil fuel consumption with income. However, if forward shifting can be fully avoided (e.g., through price controls) the burden will fall to the capital owner. In reality, as Shah and Larsen (1992) argue, forward shifting would only be partial, and the effect of a carbon tax may be progressive, as they showed with the case of Pakistan. In developing countries, such factors as market power, price controls, import quotas, rationed foreign exchange, the presence of black markets, tax-evasion, and urban-rural migration, may cast doubt on the regressivity of environmental policies (Shah and Larsen (1992), p. 8).

Boyce et al. (2005) suggest the same thing, as they mention that whether these findings can be generalised to the developing countries of Asia, Africa, and Latin America is an open question because patterns of household expenditure and energy use in developing countries are likely to differ from those of industrialised countries. OECD (1995, p. 25) even conjectures that the net effect of adding a carbon tax in developing countries may well be proportional to income, or even progressive.

The study by Shah and Larsen (1992), although no longer recent, is very comprehensive, because it includes developing countries like India, Indonesia, and Pakistan. The study attempts to quantify the efficiency and equity implication of carbon taxes for a few selected developing countries. It is unfortunate that there are almost no subsequent studies to provide enrichment of the literature on the equity impact of environmental policies in developing countries.

Shah and Larsen (1992) examine the case for carbon taxes in terms of their revenue potential, efficiency, and distributional implications. A small fossil fuel carbon tax of the order of US$10/ton is selected. However, the distributional implication is only analysed for the Pakistan case. The illustration for Pakistan uses four different cases. For the first case of ‘full forward shifting’ where the price increase is perfectly translated into final consumer prices, Shah and Larsen (1992, p. 8) show that “the carbon tax burden falls with income, thereby yielding a regressive pattern of incidence. Such regressivity is, nevertheless, less pronounced with respect to household expenditure”. However, with only partial forward shifting the results suggest “roughly proportional incidence of carbon taxes .. and a progressive incidence pattern.” Shah and Larsen (1992, p. 10) conclude that the regressivity of carbon taxes should be less of a concern in developing countries than in developed countries.

Another recent study from developing countries is by Corong (2007), where he studies the economic and poverty impact of a voluntary carbon reduction for the Philippines. He uses a static Computable General Equilibrium (CGE) model calibrated to the 1994 Philippine Social Accounting Matrix (SAM) and linked to household survey data. The approach is transferring the change in household disposable income and the cost of a household specific consumer basket (per household groups) from the CGE model into the household level data.

Amongst three scenarios in the study, one is the imposition of a 385 peso carbon tax per ton of carbon emissions, with the government recycles the generated carbon revenue by reducing income taxes imposed on households.

However, there is no discussion on the impact of the scenario on inequality because the focus is more on poverty. The result suggest national poverty incidence increases marginally as a results of the carbon tax.

Another developing countries study found in the literature is a study for China by Boyce et al. (2005). This study analyses the distributional impacts of carbon charges and revenue recycling in China, using data from 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 these categories to estimate the carbon usage embodied in these different types of household consumption.

The policy simulated is a charge of 300 yuan per metric ton of carbon. The result suggests that even without revenue recycling the effect of a carbon charge would be progressive. Boyce et al. (2005) report that the lowest decile pays 2.1% of their total expenditures, while the highest decile pays 3.2%. They suggest that this reflects the fact that the mix of products that relatively rich people buy is, on average, more carbon intensive than what relatively poor people buy.

The authors conclude 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 – particularly where rural areas are relatively poor, consume few industrial products and obtain much of their direct energy use from firewood and other.

The discussion of what would primarily drive the distributional impact of environmental policy in general or a carbon tax or energy-related policy in particular, it seems that the expenditure pattern is seen as the main driver of the results. For example, some of the literature in developed countries mentions that domestic energy such as heating could drive the effect to be more regressive, while vehicle fuels or transport tends to have less regressive effects[11].

However, environmental policy may also have an effect on household income through changes in factor prices or employment caused by the restructuring of the output composition. Hardly any studies address this issue in conjunction with the expenditure pattern. Amongst the reasons is that to complete the story, it may be necessary to address it in a general equilibrium framework using a CGE model that has disaggregated households built in or integrated in the model. Most studies use household level data only, or if using a CGE model is usually linked with the household level data, but not in an integrated manner. The main contribution offered in this paper, i.e., by applying a CGE model that can incorporate both expenditure and income pattern as inseparable driving forces in the distributional story.

3. METHODOLOGY: COMPUTABLE GENERAL EQULIBRIUM MODEL

3.1. Model Structure

The CGE model is built based on 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. For more detail about the specification of the model, please see Appendix. The important feature of the model, that also involve important modification to the standard ORANI-G model are the following.

The first modification is to allow substitution among energy commodities, and also between primary factors (capital, labor, and land) and energy because the standard model treats energy commodity as among intermediate inputs under Leontief production function, therefore, it does not allow price-induced energy substitution[12]. In this respect, this model has 38 industries, and 43 commodities with detail energy sectors. Energy commodity include coals, natural gas, gasoline, automotive diesel oil, industrial diesel oil, kerosene, LPG, and other fuels.

Secondly, the model incorporates carbon (CO_2) emission accounting, and a carbon taxation mechanism.[13] In this paper, only CO_2 emissions from fossil-fuel burning is included, meaning that it excludes

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[11] For example Pearson and Smith (1991) and Tiezzi (2001).

[12] This modification is more or less similar to the modification in the INDOCEEM (Indonesian Comprehensive Economic and Energy Model) model, another ORANI-G based model built by Monash University and Indonesian Ministry of Energy.

[13] This modification, follow closely the treatment in MMRF-Green model, as described in Adams et al. (2000).

other source of CO_2 emission such as from land-use change or deforestation. Data on detailed emissions by sector and by type of fuel for Indonesia are not available. However, Statistics of Indonesian Energy Balance, reports the detailed consumption of fossil-fuel by type of energy (natural gas, coal, gasoline, diesel, kerosene, LPG, others) in energy unit[14]. From the data on energy consumption measured in unit of energy, the amount of CO_2 emissions can be calculated. Later on, by assuming that all users of energy face the same prices[15], using the Social Accounting Matrix data with detailed consumption of energy by various industries and households and by type of energy, a matrix of CO_2 emissions by fuel type, and by users (industry and households) or $E_{f,u}$ can be calculated. More specifically, the matrix can be calculated as:

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

where $E_{f,u}$ is the CO_2 emission by energy type f, consumed by user u, in tons, $Q^E_{f,u}$ is the quantity of energy consumption by energy type f, consumed by user u, in energy unit (Barrel of Oil Equivalent/BOE), ϕ is a factor to convert BOE to Giga-Joules, CC_f is the carbon content of energy type f in ton of carbon per Giga-Joules (tC/GJ), ϖ_f is the oxidation factor by energy type, i.e., fraction of carbon oxidised, and δ is a constant (44/12) that transform carbon (C) into CO_2 emissions. Data on the quantity of energy consumption by energy type ($Q^E_{f,u}$) is obtained from Statistics of Indonesian energy balance 2003, whereas ϖ_f, CC_f, ϕ are obtained from the database of International Panel on Climate Change (IPCC).

Following Adams et al. (2000), the government revenue from CO_2 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 rupiah per ton of CO_2), and $E_{f,u}$ is the quantity (tones) of emission of CO_2 by energy type f and by user u. Because the emission tax will be imposed as 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 an *ad valorem* tax rate, P_f is the (basic) price of fuel f, and $Q_{f,u}$ is the quantity of energy consumed by user u. For every energy type f and user u, the specific CO_2 tax can be translated into an ad-valorem fuel/energy tax as follow:

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

Part of the equation 4 can also be defined as emission intensity per Rupiah use of energy (EI_{fu}), that is:

$$EI_{fu} = \frac{E_{f,u}}{P_f Q_{f,u}}. \tag{5}$$

For any specific price of carbon (or carbon tax) the impact of a specific carbon tax on the *ad valorem* tax rate for each energy type depends not only on technical or chemical matter such as its carbon content, but also on economic variables or market conditions such as prices.

Thirdly, multi-household feature is added to the standard model which only has single household. The multi-household feature is not only added to the expenditure or demand side of the model[16], but

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[14] In this case, Barrel of Oil Equivalent (BOE).

[15] One of the causes of the variation of the prices is regional variation. However, most of the price of energy products are adminstered, and the regional variation is due to transportation margin. Because the transaction in the SAM used in disaggregating the quantity of energy use is in basic price (or producer price), the common price assumption could be plaussible. Another adjustment is also made for taking into account different price paid by households and industries due to fuel subsidy.

[16] Such as done for some of other ORANI-G version.

also from the income side of the households[17].

3.2. Social Accounting Matrix

The properties of the CGE model very much depend on the Social Accounting Matrix serving as its database. A Social Accounting Matrix (SAM) is a matrix representation of transactions in a socioeconomic system[18]. It is a comprehensive, flexible, and disaggregated framework, which elaborates and articulates the generation of income by activities of production and the distribution and redistribution of income between social and institutional groups (Round, 2003).

The Indonesian Social Accounting Matrix, constructed in this study constitutes the biggest and most disaggregated Indonesian SAM yet constructed at the sectoral and household level, hence contributing to the literature on SAM construction especially for developing countries.

With the SAM that takes into account detailed household disaggregation, the CGE model not only allows for simultaneously taking into account both the income and expenditure pattern as inseparable driving forces in the distributional story in an economy-wide framework, but also allows for more direct and accurate calculation of inequality indicators and poverty incidences.

Indonesian Social Accounting Matrix 2003 serves as the core database to the CGE model. The distributional impact of policies analyzed in the CGE modelling framework have been constrained in part by the absence of a Social Accounting Matrix (SAM) with disaggregated households. Since Indonesian official SAM does not distinguish households by income or expenditure size, it has prevented accurate assessment for the distributional impact, such as calculation of inequality or poverty incidence. The SAM used in this paper, is a specially-constructed SAM representing Indonesian economy for the year 2003, with 181 industries, 181 commodities, and 200 households (100 urban and 100 rural households grouped by expenditure per capita centiles) was constructed. The SAM (with the size of 768x768 accounts) constitutes the most disaggregated SAM for Indonesia at both the sectoral and household level.

The construction of the SAM is a lengthy process and will not covered in this paper. The nature of constructing specifically-designed SAM with distributional emphasis not only require large-scale household survey data but also involved reconciliation of various different data sources. Interested readers can refer to Yusuf (2006). The structure of the SAM can be seen from table 1.

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[17] More or less similar modification to ORANI-G model has been made to the very popular WAYANG model, an ORANI-G based Indonesian CGE model.

[18] A Social Accounting Matrix is an essential database for computable general equilibrium (CGE) modelling. In a SAM framework every agent's expenditure has to equal its receipt (in the form of equality between column and row sum), so that a SAM explicitly represents the initial equilibrium, or market clearing conditions in the economy. Every good and service produced by industry is equal to what is demanded. Each factor of production supplied has to be absorbed by industry, and household spending has to be equal to income. An exercise using a CGE model, is basically comparing this initial equilibrium condition, with other equilibrium induced by changing exogenous shocks to the model.

TABLE 1

Structure of 768×768 Indonesian SAM

			Commodity		Factor									
		Activities 1⋯181	Domestic 1⋯181	Imported 1⋯181	labour 1⋯16	Capital	Ind. Tax	S-I	Households 1⋯200	Transfers	Enterprises	Gov't	ROW	TOTAL
Activities	1 ⋯ 181		MAKE Matrix											Industry Sales
Domestic Commodities	1 ⋯ 181	Domestic Intermediate Input						Domestic Investment	Domestic Hou. Consumption			Domestic Gov't Consumption	Export	Total Dom. Demand
Imported Commodities	1 ⋯ 181	Imported Intermediate Input						Imported Investment	Imported Hou. Consumption			Imported Gov't Consumption		Total Import
labour	1 ⋯ 16	Salary and Wages											labour used abroad	Total labour Demand
Capital		Non-labour											Cap. used abroad	Capital Demand
Ind. Tax		Tax/ Subsidy		Tariff										Ind. Tax Reven.
Urban HH	1 ⋯ 100				labour Income: Urban	Capital Income: Urban				Inter-Hous. Transfer			ROW transfer to HH	Total Hous. Income
Rural HH	1 ⋯ 100				labour Income: Rural	Capital Income: Rural				Inter-House. Transfer			ROW transfer to HH	Total Hous. Income
Transfer									Transfer to HH					Int. Hou. Transfer
S-I									Household Saving		Enterprise Saving	Gov't Saving		Total Saving
Government							Ind.Tax Revenue		Direct Tax		Ent. Trans. to Gov't	Inter G Transfer	ROW Tans. to Gov't	Govt Revenue
Enterprises						Enter-Capital					Inter Ent. Trans.		ROW Trans. to Enter.	Ente. Income
ROW				Import	Foreign labour	Foreign Capital			HH Transfer to abroad		Ent Trans. to abroad	G. Transfer to abroad		Forex Outflow
TOTAL		Industry Costs	Dom. Supply	Import Supply	labour Supply	Capital Supply	Ind. Tax Revenue	Total Invest.	Household Spending	Int. Hou. Transfer	Enter. Spending	Govern. Spending	Forex Inflow	

The detail SAM used in this model not only provide detail household disaggregation, but also detail labor classification acknowledging the typical characteristics of labor market in developing countries like Indonesia. The Social Accounting Matrix distinguishes 16 classifications of labour. It recognises 4 skills types (agricultural, non-agricultural unskilled, clerical and services, and professional workers), urban-rural distinction, and formal and informal (unpaid) workers. Together, it distinguishes 16 labor categories.

Standard official SAM relies on the Input-Output table. However, the Input-Output table, only distinguishes a single type of labour recorded in the wage bills of industrial costs. Gross operating surplus is then calculated as residuals. In developing countries, where a significant portion of industry does not officially record all payments to labour, this practice, may lead to misleading information.

First, the economy will appear to be highly endowed with capital, which is unlikely to be the case for developing countries like Indonesia. For example, from the Input-Output table, compensation of employees in Indonesia only accounts for around 35% of value added, whereas in the European Union, for example, the number is around 65%[19].

Second implication, is that certain industries which are supposed to be relatively labour intensive (e.g., agriculture compared with manufacturing) will instead appear to be capital intensive. Factor intensity is a very important driver of behaviour in the CGE model. For example, the parameters of most production functions used in the CGE model are function of factor shares. The reliability of some CGE models which rely purely on Input-Output table with understatement of labour, will be in question[20]. Understatement of labour compensation is quite common in a developing country Input-Output table. Cororaton (2003), for example shows the case for the Philippines.

The SAM constructed for this research has incorporated the above overlooked aspects utilizing both nation-wide data, as well as detail information from large-scale household survey data.

3.3. Closure

There are at least three considerations in specifying the closures for the simulations. First, the closures have to be able to accommodate the research questions specified. For example, when the research objective is to find out the aggregate welfare impacts of particular shocks, then aggregate real consumption, as indicator of welfare, has to be one of the endogenous variables. For example, as Horridge (2000) stated, the choice of closure is affected by the needs of a particular simulation. Second, the closure should also be able to minimise the weakness due to the feature of the real world that cannot be explained by the model. For example, because the model is static, to avoid the inter-temporal allocation of welfare impact, at the expenditure side, the real investment and the trade balance should be treated as exogenous (Warr, 2001). Finally, the closure is associated with the idea of the simulation timescale, meaning the period of time which would be needed to adjust to a new equilibrium (Horridge, 2000). The objective is to specify the closure as realistic as possible, representing the particular economy, and accommodating the research questions to be investigated.

In specifying a macroeconomic closure, on the aggregate demand side, aggregate real investment, aggregate real government consumption, and trade balance (in real terms) are treated as exogenous, whereas the aggregate real consumption is endogenous hence can be interpreted as the aggregate index of welfare. This prevents, for example, inter-temporal allocation of welfare impact, due to capital accumulation that may increase welfare in the future (Warr, 2001).

At the fiscal side, for some scenarios of 'revenue-neutral' carbon tax, the government budget surplus/deficit is exogenised. The variable that is used to balance the government budget is general sales

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[19] Source: GTAP Database.

[20] Standard WAYANG model, for example, is based mainly on Indonesian Input-Output table which records around 34.36% of the aggregate labor share (source: Wayang 2002 database).

tax rate, or the amount of cash compensation to households, depending on the simulation objectives.

In the factor market closure, capital is specific, can not mobile across sectors, and the industry-specific price of capital is the equilibrating variable. Labor is mobile across industries, however, aggregate employment is exogenous, a typical neoclassical closure with full employment. The analysis will use a closure with the neoclassical full-employment assumption in the labour market. The real wages are endogenous serving as the equilibrating variable to satisfy the full employment conditions. The limitation of this closure is that the carbon tax will have a low impact on GDP because factors of productions are constrained from the supply side. Impact on GDP from a carbon tax is usually channeled through its impact on employment or capital stocks. However, because the focus of the case study is on its distributional implication channeled through the changing factor prices from resource reallocation, fixity of factors on the aggregate level is less of a concern.

3.4. Method for Analyzing Distributional Impact

In the literature, there are various approaches for dealing with the income distribution analysis in a CGE model. The traditional one is the representative household method where it is assumed that the distribution of income or expenditure follows a certain functional form[21]. The distribution is assumed to remain constant before and after the shock. One of the weaknesses is that the behaviour of a group of households is usually dominated by the richest. There has been growing evidences to suggest that the variation within one single household-category is important and can significantly affect the results of the analysis (Decaluwé et al., 1999). Household-specific shocks, such as transfers to targeted household groups, are also impossible to carry out using this approach. Studies for Indonesia by Sugema et al. (2005) and Oktaviani et al. (2005), among others, belong to this type of approach.

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 Clements et al. (2003) Resosudarmo (2003), Azis (2000), and Azis (2006), among others, follow this approach.

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 and income-generation model. Price changes are exogenous in this micro-model, hence the endogeneity of prices is ignored. Studies for Indonesia by Bourguignon et al. (2003) and Ikhsan et al. (2005) are in the class of this type of approach. Some attempts has been made to improve this approach by providing a feedback from the micro-model to the CGE model. Belonging to this category among others are studies by Filho and Horridge (2004) for Brazil, and Savard (2003) for the Philippines.

The most recent approach is multiplying the number of households into as many as households available in the household level data. Increasing computation capacity allows a large number of households to be included in the model. It allows the model to take into account the information from the household data in greater detail avoiding pre-judgment about aggregating households into categories. All prices are endogenously determined by the model and no prior assumption of any distribution parameter is necessary. Drawbacks of this approach are the difficulties of data reconciliation and the fact that the size of the model can become a computational constraint. This integrated-microsimulation-CGE model has been used in various studies including Annabi et al. (2005) for Senegal, Plumb (2001) for U.K., Cororaton and Cockburn (2005) and, Cororaton and Cockburn (2006) for the Philippines.

The last approach, to be used in this paper, is disaggregating or increasing the number of household categories by the size of expenditure or income per capita. If the categories is detailed enough, such as 100 centiles, the distributional indicators such as poverty incidences or standard inequality indicators

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[21] For example, log-normal distribution.

can be estimated more precisely. For example, Warr (2006) used this approach for Laos in assessing the poverty impact of a large scale irrigation investment.

The ideal approach in distributional analysis where disaggregated households are integrated in the CGE model is when all observations in the household survey are integrated in the model like in the Micro-simulation CGE models. It turns out that using only 100 representative household classified by centile for expenditure per capita, the calculation of poverty and inequality indicator could be fairly accurate[22].

In this study, poverty incidence, for example, is simply calculated using the following formula. Let y_c is real expenditure per capita of household of the c-th centile where $c = 1, \ldots, n$, and $n = 100$. Poverty incidence then is calculated using

$$P\left(y_c, y_P\right) = \max\left\{c | y_c < y_P\right\} + \frac{y_P - \max\left\{y_c | y_c < y_P\right\}}{\min\left\{y_c | y_c > y_P\right\} - \max\left\{y_c | y_c < y_P\right\}}$$

where y_P is the poverty line. The first term is simply the centile of of which expenditure per capita is the closest from the origin (the left) to the poverty line. The second term is the linear approximation of the decimal point of the poverty incidence.

The change in poverty incidence after a policy shock (simulation) is calculated as

$$\Delta P = P\left(y'_c, y_P\right) - P\left(y_c, y_P\right)$$

where

$$y'_c = \left(1 + \frac{\hat{y}_c}{100}\right) \cdot y_c$$

where $\hat{y}_c$ is the percentage change in *real* per capita expenditure of household of the centile c produced from the simulation of the CGE model. The change in the real expenditure per capita across household will be used to investigate ex-ante distribution (before the policy change) and ex-post distribution (after the policy change).

4. SCENARIO AND SIMULATION STRATEGY

In contrast to developed countries who have a legal commitment under the Kyoto Protocol to cut CO_2 emissions, Indonesia does not yet have to follow a certain scenario of emission reduction. In this case study, a carbon tax of Rp. 280,000 per ton of CO_2 emission[23] is introduced with three different scenarios of revenue-recycling[24].

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

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), implementation of a carbon tax will be accompanied by a reduction in the uniform general *ad valorem* sales tax rate for all commodities, such that government revenue is in balance. To do this, a uniform sales tax shifter would be endogenised while government

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[22] Calculation of Gini coefficient is carried out for the whole 29,278 sample of urban households from SUSENAS and using only 100 households grouped by centile of expenditure per capita. The results are almost identical.

[23] Around US$ 32.6.

[24] A carbon tax of this amount is chosen to reduce emissions by 6.6%, i.e., the Indonesian historical growth rate of emission. So, essentially, this is a scenario of emission stabilisation. An arbitrary carbon tax can always be set, such as being equal to the social cost of carbon from the literature, or any level, but the direction of the distributional result, which is the focus of this chapter, will not significantly change.

saving is exogenised. The other relevant scenario for the revenue-recycling mechanism is to give a uniform lump-sum transfer to all households. This will be the third scenario (SIM 3).

Another option is a reduction in the income tax rate, as widely discussed in the 'double-dividend-hypothesis' literature. This alternative is not implemented in this exercise for at least two reasons. First, for the double dividend hypothesis to work, it is necessary to have an endogenous labour supply, which is not specified in the CGE model. Second, income (especially labour income) tax collection in Indonesia is low in terms of population coverage, making the likelihood of reducing the income tax rate less feasible.

5. RESULTS AND DISCUSSION

The summary of the macroeconomic, emission, and factor market result is shown in Table 2, whereas Table 3 shows the results on industry output and the prices of several relevant commodities.

GDP, as well as consumption expenditure (which can be treated as an indicator of aggregate welfare) fall slightly in all three scenarios. However, the simulation suggests that SIM 2, where revenue from the carbon tax is returned to the economy as the uniform reduction in commodity tax rate, produces the lowest decline in welfare effect, where real aggregate consumption falls by only 0.03 percent. A reduction in the commodity tax rate, following the carbon tax implementation, minimises the impact on commodities prices, as can be seen in Table 3, from the lowest CPI percentage increase of 0.58%. This creates an expansionary effect on the economy because of the increase in the demand for commodities and the resulting output expansion. The uniform cash transfers (SIM 3) to all households do not generate as much expansionary pressure on the domestic economy as the reduction in commodity tax, although it may have a better distributional outcome.

The immediate effect of introducing carbon tax is an increase in the price of energy products because the carbon tax is implemented through an increase in the *ad valorem* tax rate on energy commodities, the magnitude of which depends mainly on their carbon content. The price of coal rises most (by more than 100%), followed by other energy and closely-associated products such as electricity and transportation.

Energy related sectors are hurt the most. For example, in SIM 1, output of petroleum refinery and coal mining fall by 3.9% and 2.9%, respectively. Other related sectors to experience significant contraction are natural gas, LNG, electricity, water and gas, road, and other transportation sectors.

In terms of factor reallocation, the simulations suggests that, in general, following implementation of the carbon tax, the energy and capital intensive manufacturing sectors tend to contract while agriculture and service sectors tend to experience a slight expansion. Resources have been reallocated from the energy sectors, most non-food manufacturing industries and utility sectors, to agriculturally-based sectors (such as paddy, other crops, and wood sectors), and to some food-manufacturing sectors and services sectors (such as hotel and restaurants).

As indicated in Table 4, industries which experience a significant decline in output are relatively energy intensive. Other than energy sectors (petroleum refinery, coals, crude oil, and natural gas), these industries are, among others, LNG, chemical products, pulp and paper, nonferrous metal, electricity, water and gas, construction, and transportation. As Table 4 also reveals, most of these industries are also capital intensive. This structural change would affect the functional distributional of income, by the tendency to reduce the return to capital more than to other factors. In turn, this would tend to hurt households proportionately more endowed with capital.

The changes in the return to factors as shown in Table 2, clarify these points. The adjustment in the production sectors affects the prices of factors. In general, the capital owner is hurt more compared with other factors. The return to capital declines the most, followed by real wages, and return to land. In all scenarios, the return to capital falls. In the labour market, for SIM 1, real average return to capital falls most by -5.77%, while the return to land falls by only 0.41%, and the fall in real wages varies depending

TABLE 2
Simulated Macroeconomic, Emission, and Factor Market Effects of a Carbon Tax

	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	1.70	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	-4.10
Clerical, rural, informal	-1.76	2.11	-1.64
Clerical, urban, informal	-1.78	2.05	-1.93
Professional, rural, formal	-3.19	0.50	-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

on skills, but it is always much less than the fall in the return to capital. Real wages fall more for urban and formal skilled labour, reflecting the contraction in the industries employing this labour more intensively. The real wage of urban formal production workers (mostly employed in the manufacturing sectors), urban formal clerical workers, and urban formal professional workers falls the most, by 4.6%, 3.1%, and 3.5%, respectively. On the other hand, agricultural labour only experiences a slight fall in real wages. This adjustment in the factor market will have an important impact because it can drive the distributional effect of a carbon tax to be more progressive from the income side.

As far as the macroeconomic impact or aggregate welfare is concerned, the revenue recycling mechanism in the form of lump-sum transfers is inferior to a commodity tax cut, given the same neutrality of the government budget. One possible explanation for this is that even though a lump-sum transfer for a rural household is a windfall, the economy is driven more by the spending of richer households. Therefore, a uniform tax rate cut for all commodities is more expansionary through the resulting increase in the demand for commodities.

5.1. Distributional results

Table 5 shows the summary of the distributional effect of a carbon tax for all three scenarios. In the table, both the poverty effect, indicated by the change in the head count poverty incidence, and inequality effect, indicated by the change in the Gini coefficients, are shown for urban, rural, and urban + rural households. Figure 2 illustrates in greater detail how each simulation affects household incomes, the household specific CPI, and household real expenditures across urban, rural, and expenditure classes.

In general, the simulations suggest that the introduction of a carbon tax in Indonesia would hurt urban households than rural households. Its impact in rural areas would be progressive, suggesting the

TABLE 3
Simulated Industry and Prices Impacts of Carbon Tax

	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	-0.30	-0.28
Natural gas	-0.69	-0.69	-0.69
Other mining	-0.10	-0.23	-0.08
Rice	0.10	0.10	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	-0.20	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	-0.50	2.45	-0.22
Automotive industries	0.35	-0.08	-0.47
Other manufacturing	0.20	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	0.30	0.10	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	0.10
General government	0.00	0.00	0.00
Education	0.11	0.06	0.04
Health	0.31	0.17	0.49
Entertainment	0.60	0.49	0.23
Other services	0.29	0.04	-0.25
Prices of commodities			
Coal	131.80	131.95	132.47
Natural gas	26.35	27.27	26.50
Gasoline	24.61	24.72	24.59
Diesel (Automotive)	45.31	45.56	45.44
Diesel (Industries)	43.48	43.83	43.67
Kerosene	29.30	29.54	29.93
LPG	25.62	26.28	24.71
Other fuels	21.37	21.90	21.46
Electricity	16.93	16.97	17.38
Water and gas	12.38	12.13	12.16
Road transportation	1.77	1.30	1.58
Other transportation	2.36	1.00	2.31
CPI	1.32	0.58	1.75

TABLE 4

Cost Share of Industries and Changes in Output

	Share of total input					Change in
	labour	Capital	Land	Energy	Oth. Int	Output
Paddy	51.40	16.56	14.50	0.00	17.54	0.09
Other food crops	57.36	17.35	15.20	0.01	10.09	0.05
Estate crops	52.73	11.21	8.88	0.29	26.89	-0.13
Livestock	42.39	8.08	3.41	0.03	46.08	0.13
Wood and forests	36.37	21.78	21.34	0.42	20.09	0.09
Fish	38.96	8.77	27.19	1.98	23.09	-0.08
Coal	8.09	72.01		13.17	6.73	-2.94
Crude oil	5.80	80.74		6.41	7.06	-0.29
Natural gas	5.81	80.97		6.44	6.77	-0.69
Other mining	26.38	47.48		2.16	23.98	-0.10
Rice	6.17	8.32		0.02	85.49	0.10
Other food (manufactured)	15.23	18.59		0.84	65.34	0.15
Clothing	14.58	19.10		0.83	65.48	0.41
Wood products	18.24	25.36		1.05	55.35	0.23
Pulp and paper	13.92	22.79		1.51	61.79	-0.07
Chemical product	11.88	14.70		3.56	69.86	-0.66
Petroleum refinery	7.54	57.83		8.04	26.60	-3.87
LNG	1.66	51.77		40.05	6.51	-2.89
Rubber and products	15.80	14.82		1.82	67.56	-0.20
Plastic and products	7.81	20.26		0.82	71.11	-0.05
Non-ferous metal	20.40	34.71		6.82	38.07	-1.61
Other metal	9.90	14.06		1.79	74.26	-0.37
Machineries	9.35	13.31		0.63	76.71	-0.50
Automotive industries	15.67	29.73		0.80	53.80	0.35
Other manufacturing	14.06	26.56		1.40	57.98	0.20
Electricity	5.92	50.14		19.33	24.62	-1.44
Water and gas	17.27	26.37		13.42	42.93	-2.24
Construction	23.09	9.55		4.76	62.60	-0.01
Trade	35.27	26.83		1.48	36.42	0.05
Hotel and restaurants	36.93	10.99		0.04	52.04	0.30
Road transportation	21.40	22.11		8.31	48.17	-0.66
Other transportation	12.48	18.17		10.33	59.01	-1.44
Banking and finance	18.90	53.47		0.25	27.38	0.23
General government	53.98	5.62		2.14	38.26	0.00
Education	43.72	8.54		1.10	46.65	0.11
Health	54.50	9.02		0.19	36.29	0.31
Entertainment	17.24	18.11		0.10	64.55	0.60
Other services	25.06	34.83		0.31	39.79	0.29

TABLE 5
Simulated Distributional Effect of a Carbon Tax

	SIM 1 No-revenue recycling	SIM 2 Uniform cut on com. tax rate	SIM 3 Uniform transfers
Urban			
Ex-ante Poverty Incidence	13.600	13.600	13.600
Ex-post Poverty Incidence	13.768	13.613	12.915
Change in Poverty Incidence	0.168	0.013	-0.685
Rural			
Ex-ante Poverty Incidence	20.200	20.200	20.200
Ex-post Poverty Incidence	19.430	19.743	16.198
Change in Poverty Incidence	-0.770	-0.457	-4.002
Urban + Rural			
Ex-ante Poverty Incidence	17.194	17.194	17.194
Ex-post Poverty Incidence	16.852	16.951	14.703
Change in Poverty Incidence	-0.343	-0.243	-2.492
Urban			
Ex-ante Gini Coefficient	0.347	0.347	0.347
Ex-post Gini Coefficient	0.347	0.347	0.337
Change in Gini Coefficient	0.000	0.000	-0.010
Rural			
Ex-ante Gini Coefficient	0.277	0.277	0.277
Ex-post Gini Coefficient	0.274	0.275	0.260
Change in Gini Coefficient	-0.003	-0.002	-0.017
Urban + Rural			
Ex-ante Gini Coefficient	0.350	0.350	0.350
Ex-post Gini Coefficient	0.347	0.348	0.333
Change in Gini Coefficient	-0.003	-0.002	-0.017

poor would gain relatively more than the rich, whereas in urban areas its distributional direction depends on how the revenue from a carbon tax is recycled. It is relatively neutral for the case of no-recycling and tax rate reduction, but progressive for the case of uniform lump-sum transfers. The overall net-impact nationwide is progressive for all scenarios, as can be seen from the reduction in the Gini coefficient.

General results from the simulations suggest that almost all rural households experience a welfare gain as their real expenditure per capita rises. As can be seen from figure 2, these gains are distributed progressively, as the percentage changes in the welfare of poorer households are higher than for richer households. However, in simulations 1 and 2, almost all urban households are worse-off, and the effect is more or less neutrally distributed, while in simulation 3, the lowest 20% are better-off, and the distributive effect is progressive.

The driving forces behind these results are closely related to the impact of a carbon tax on both commodity prices and factor prices, combined with a distinct pattern of consumption and factor endowments for each household. From the simulations, it may be suggested that within the same expenditure class, households in rural areas tend to gain more (or to lose less) than households in urban areas. Both in urban and rural areas, poor households tend to gain more (or to lose less) than rich households, and the rural poor tend to gain greater benefit (or a smaller loss) than the urban poor.

One of the contributing features of the CGE model with full-integration of disaggregated households is that it can reveal what causes the distributive effect from both the expenditure and the income pattern. Unlike a partial equilibrium analysis, which only looks at the demand side and is associated only with the expenditure pattern of the households, or even a CGE model with a separate top-down micro-simulation model, the CGE model used in this study is able to offer deeper analysis on its distributive effect from the income side. From the story of the industry results, the factor reallocation in the economy tends

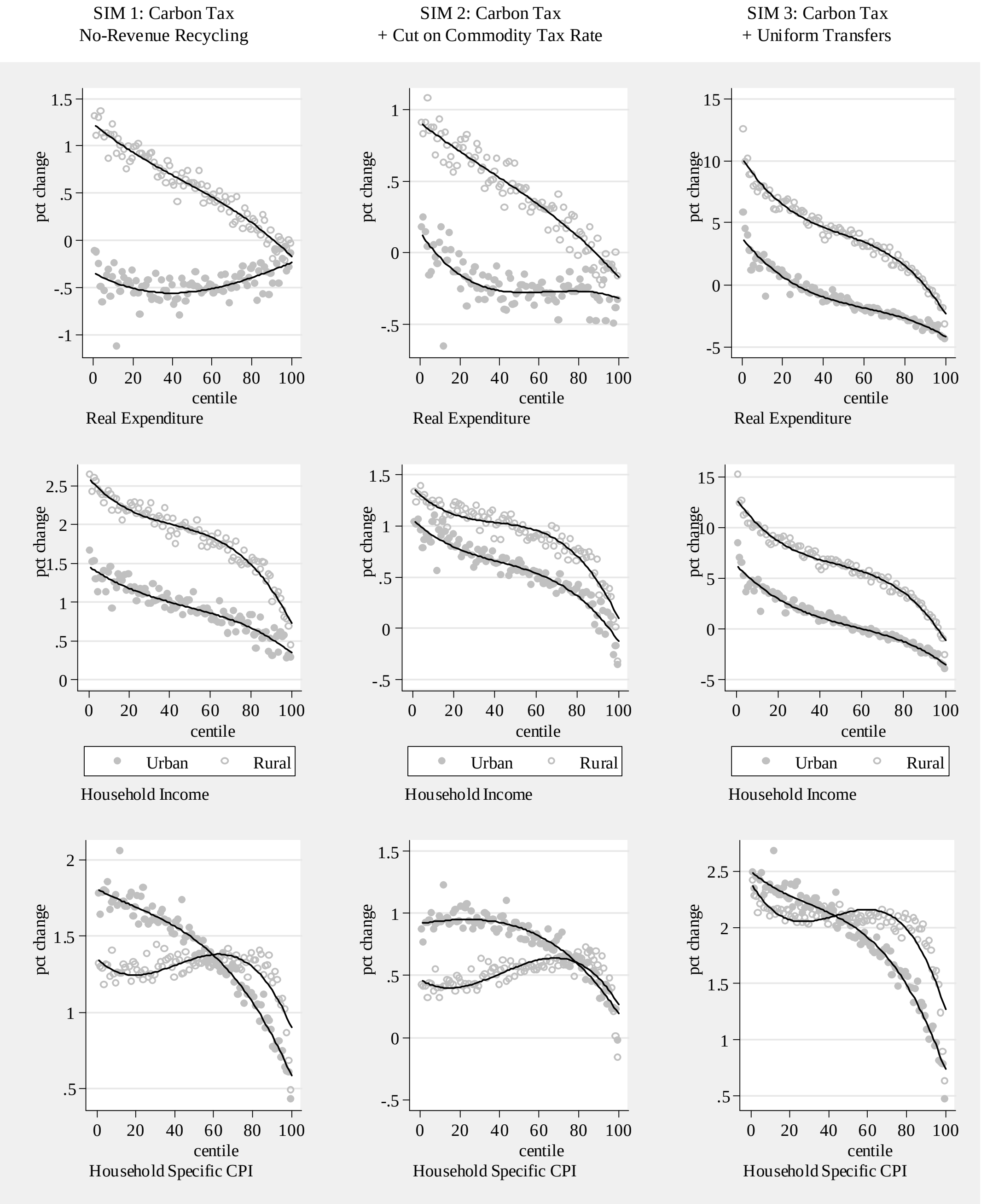

FIG. 2 Simulated impact on households' real expenditure, income, and households' specific CPI

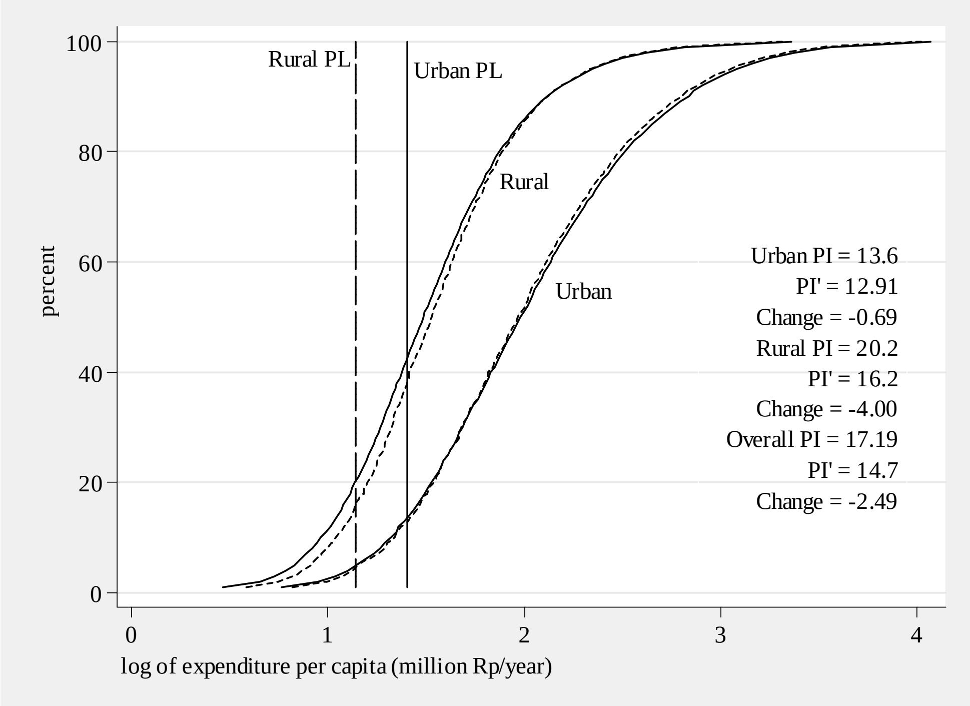

FIG. 3 Simulated Poverty Impact of a Carbon Tax (SIM 3)

to be biased against capital and skilled labour, and in favor of the agriculture and the services sectors, and hence agricultural, unskilled, and informal workers. This may explain why its distributive effect is progressive from the income side of households. As can be seen from Figure 2, in all scenarios, the percentage change in household incomes is clearly declining (suggesting progressivity) as expenditure centiles rise, both in rural and urban areas. Meanwhile, rural households' incomes, in general, increases more than urban household incomes.

This result is more or less explained by the typical characteristic of a developing country economy, where abundant unskilled and prevalently rural labour are employed in less energy-intensive and less capital-intensive sectors. In general equilibrium 'mechanics', there would be factor reallocation from energy-intensive sectors (which are mostly also capital intensive) into less energy-intensive (and less capital-intensive) sectors such as agriculture. Expansion in these sectors would have favourable distributional consequences in a developing country like Indonesia. For example, as shown before, the return to land, and the return to informal, unskilled, rural, agricultural workers rise relative to the return to capital or to formal skilled workers. This would drive the favourable distributional impact from the income side, as also illustrated by the declining percentage change in (nominal) income over expenditure centile both in urban and rural areas.

It may be expected that the characteristics of the economy are different in more developed countries, where most of the sectors are energy-intensive, capital-intensive and less agricultural. This may explain why the distributive effect of a carbon tax in developed countries has been reported in various studies as generally regressive. This study shows that the distributive effect of a carbon tax in developing countries may not necessarily be the same. This is still the case even if only looking at the income side pattern of households, which is related to typical factor market features in developing countries.

Moreover, the other side of the story is that the consumption basket of poorer households in Indonesia tends to be less energy intensive. For example, electricity usage, not to mention vehicle ownership, is not as common as in richer countries. So, there is an expectation that progressivity may also originated from the expenditure side.

As illustrated in the bottom panel of Figure 2, progressivity from the expenditure side could be determined if household specific CPI is increasing over the centiles, suggesting that the price paid for the total consumption bundle increases more for richer households than it does for poorer households. As shown in those figures, in rural areas this may be true from the poorest to around the 80^{th} centile, as from the 80^{th} centile, its pattern is declining. Hence, from the expenditure side, it is progressive for the lower and middle income classes.

The story is rather different in urban areas. Poorer urban households are under pressure from the expenditure side. the household specific CPI is declining over the expenditure centile in urban areas, suggesting that the price paid by poorer households for their consumption basket increases more than that paid by richer households. This means urban household consumption is more sensitive to the price of energy-related products than rural households' consumption. Among others, these products are fuels, electricity, and transportation. What drives the regressivity from the expenditure side in urban areas is actually the lower-income households dependence on domestic fuel, especially kerosene. The dependence on kerosene is explained, among others, by the high kerosene subsidy, making its price much lower than the competitive market price. In turn, the regressivity from the expenditure side, and the progressivity from the income side, drive the neutrality of the distributive effect of a carbon tax in urban areas. However, overall the nationwide distributional impact is still progressive, despite the regressivity from the expenditure side in urban areas.

With regard to the impact on poverty, because 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 most (by 4%) when the revenue from a carbon tax is returned in the form of uniform lump-sum transfers (see Figure 3). Because the rural population is a lot larger than the urban population, the declining poverty incidence in rural areas helps nation-wide poverty incidence fall in all simulations, despite increasing poverty incidence in urban areas (for SIM 1 and SIM 2).

Comparing alternative revenue-recycling schemes suggests a uniform reduction in the general commodity tax rate has a favourable aggregate welfare impact (in terms of aggregate real consumption and GDP). GDP falls the least in SIM 2, with a magnitude of half of SIM 1. However, the uniform lump-sum transfer has more favourable distributional impact and inequality falls the most nation-wide. The Gini coefficient falls significantly by 0.017 compared with only 0.002 with a uniform sales tax cut. The poverty impact of uniform lump-sum transfer is also most favourable. Poverty falls nationwide by 2.5%, which is due to the fall in rural poverty incidence of 4%, as shown in Figure 3.

However, a uniform reduction in the rate of commodity tax has a more favorable macroeconomic impact because of its potential for boosting consumption spending, as shown in the discussion of the macroeconomic impact in the earlier section. Moreover, a uniform cash transfer is not a common instrument of redistribution, and may be difficult to implement both administratively and politically.

It should also be noted that introducing a uniform reduction in commodity tax, may affect the direction of the initial distributive effect of a carbon tax when the carbon tax revenue is not recycled. First, the reduction in inequality (in terms of the reduction in Gini coefficient) is lower in SIM 2 (with tax-cut) compared to SIM 1 (no-recycling). Because the pattern of the change in the household specific CPI over the centiles from both simulations seems similar (except in its overall magnitude), it is less likely that commodity price rises contribute to the different result. This is understandable because the reduction in commodity taxes is uniform across commodities, hence will have a more or less similar impact on commodity prices. However, the pattern of the change in household income is relatively different between the two simulations. Comparing the change in income of urban and rural households, the figures show the gap between the change in income of urban and rural households is narrower in SIM 2 (tax-cut) compared to SIM 1 (no-recycling). This result may therefore suggest that what is happening in the factor market has driven the different distributional result between the two simulations.

Table 2 may help explain this result. The outputs of industries tend to fall with less magnitude in SIM 2, simply because of the increasing demand due to reduced prices brought about by a uniform sales tax-cut. The increase in demand for commodities offsets the decline in demand for labour by industries that would have happened without the tax-cut. Real wages of all types of labour rise instead of fall, and the return to capital falls much less in SIM 2 than in SIM 1. Some industries (such as pulp and paper, rubber, plastics, and machineries) manage to avoid contraction and some others contract a lot less. Most of these industries are capital intensive, and employ more intensively urban-formal production workers and so may contribute in minimising the urban bias of the distributive effect of a carbon tax. However, despite these factors, a carbon tax with revenue recycled through a uniform reduction in the general sales tax is still progressive, inequality-reducing, adding to its preferability because of its more favourable macroeconomic effects.

6. CONCLUDING REMARKS

The simulations suggest that in contrast to most studies for developed countries, implementation of a carbon abatement policy via the introduction of a carbon tax in Indonesia would not necessarily be regressive. Instead, it would be strongly progressive and robust to various alternative recycling-schemes in rural areas. It would be either neutral or slightly progressive in urban areas. Its overall distributive effect nation-wide would be progressive, as shown by the decline in inequality indicators.

A closer look at what may contribute to the favourable distributive effect of a carbon tax reveals the progressivity is driven from both household income and expenditure pattern. The resource reallocation in the economy following the introduction of a carbon tax would be in favour of factors endowed more proportionally by rural, and lower income households, as shown, for example, by contraction of the energy intensive manufacturing sectors and expansion of the agriculture and service sectors. The typical expenditure pattern in developing countries, which is less-energy-sensitive, also helps drive progressivity of the result especially in rural areas.

The results may have important global policy implications. Encouraging developing countries to reduce carbon emissions not only increases the efficiency of carbon abatement globally, but may also have a favorable distributional implication for the developing countries themselves, in contrast to a less preferable distributional impact in developed countries. Whereas a global 'efficiency gain' from shifting the location of carbon abatement from industrialised to developing countries has been widely acknowledged, this study introduces the addition notion of a 'global equity gain'.

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APPENDIX A: DESCRIPTION OF THE CGE MODEL

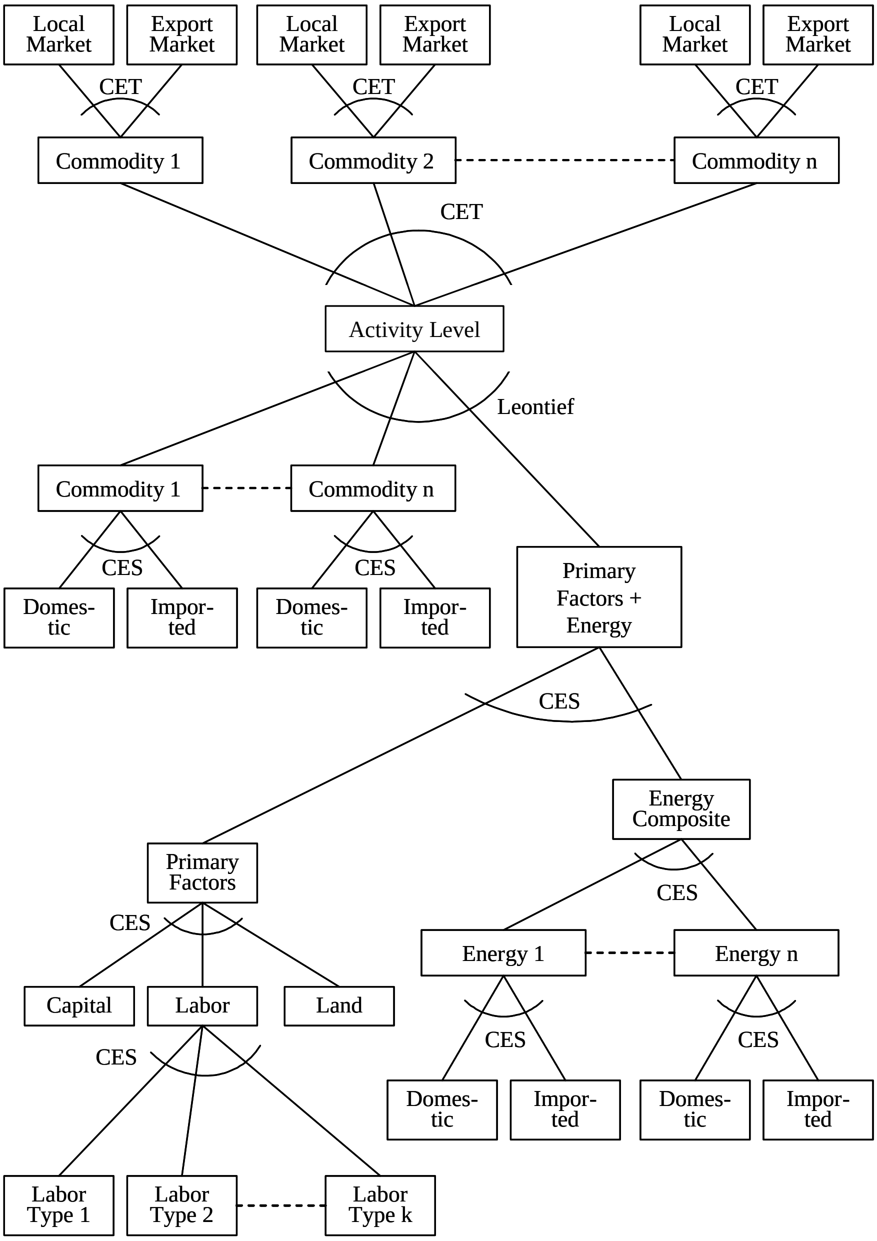

FIG. 4 Structure of Production

A.1. Production Sectors

The structure of the nested production function for each industry is illustrated in figure 4. At the very bottom part, industry choose how many each type of labor demanded and determine the number of labor composite according to Constant Elasticity of Substitution aggregation function. More formally, every industry solve the following optimisation problem,

$$\min \sum_{o} w_o L_o \text{ s.t. } \tilde{L} = \text{ CES}\left(L_1, L_2, \ldots, L_O\right)$$

where w_o is wage of each of the occupational type, L_o is the number of labor for each occupation type, and $\tilde{L}$ is labor composite, and $o = 1, \ldots, O$. In this model, the classification of the labor type is fairly detail and also represent the higher degree of dualistic nature of informality in the labor market, typical in developing countries. Therefore in this model, formal and informal labor, for example, are not perfect substitutes, and paid with different wages. This typical informality is often neglected in many others CGE model.

At the next stage, the optimisation problem for each of the industry is,

$$\min P^K K + P^N N + \tilde{w}\tilde{L} \text{ s.t. } V = \text{ CES}\left(K, N, \tilde{L}\right)$$

where K and P^K are capital and price of capital respectively, N and P^N are land and price of land respectively, and $\tilde{L}$ and $\tilde{w}$ are labor composite and its price respectively, whereas V is value added or primary factor composite.

At the other end, for every energy commodity, each industry optimise to choose the source of the commodity from either local or imported commodity, or

$$\min P_e^D E_e^D + P_e^M E_e^M \text{ s.t. } \tilde{E}_e = \text{ CES}\left(E_e^D, E_e^M\right)$$

where P_e^D and E_e^D are price of domestic energy e and quantity of domestic energy e respectively, where P_e^M and E_e^M are price of imported energy e and quantity of imported energy e respectively, whereas $\tilde{E}_e$ is domestic-imported composite of energy e.

The industry, then, choose the composition of energy type for every energy composite that they need,

$$\min \sum_{e} \tilde{P}_e \tilde{E}_e \text{ s.t. } E^C = \text{ CES}\left(\tilde{E}_1, \tilde{E}_2, \ldots, \tilde{E}_E\right)$$

where $\tilde{P}_e$ and $\tilde{X}_e$ are price and quantity of domestic-imported composite energy e, respectively, while E^C is the energy composite.

Industries are allowed to substitute between energy and primary factors, so they are solving the following optimization problem

$$\min P^E E^C + P^V V \text{ s.t. } VE = \text{ CES}\left(V, E^C\right)$$

where P^E is the price of energy composite, and P^V is the price of primary factor composite, while VE is value-added and energy composite.

At the top of the production nest, each industry minimises cost of purchasing intermediate costs and primary-factor-energy composite to produce output of the activity level using Leontief production function, or

$$\min \sum_{c} P_c X_c + P^{VE} VE \text{ s.t. } A = \min\left(X_1, X_2, \ldots, X_C, VE\right).$$

where P_c and X_c are price and quantity of intermediate commodity c respectively, where A is activity level or total output of industry.

In this model, each industry is allowed to produce multiple commodities[25], such that

$$\max \sum_c P_c X_c \text{ s.t. } A = \text{ CET}\left(X_1, X_2, \ldots, X_C\right)$$

where CET refer to Constant Elasticity of Transformation function. And finally, industry can choose to sell either in local or export market such that the optimisation problem is

$$\max \sum P_c^D X_c^D + P_c^E X_c^D \text{ s.t. } X_c = \text{ CET}\left(X_c^D, X_c^E\right)$$

where P_c^D and X_c^D are price and quantity of commodity sold to local/domestic market, whereas where P_c^E and X_c^E are price and quantity of commodity supplied to export market.

The model has 38 number of sectors and 43 number of commodities. All industry producing single commodity except petroleum refinery sector where it produces 6 type of commodities i.e., gasoline, kerosene, automotive diesel oil, industrial diesel oil, other fuels, and LPG. This is the aggregation from 181 sectors/commodities in the Social Accounting Matrix, as discussed in the earlier section. Since fuel commodities is disaggregated in detail, it can capture accurately how the October 2005 package was implemented, because the rise in the fuel prices are different across fuel commodities.

A.2. Households

Household maximise Stone-Geary Utility function (in log form),

$$U = \sum_i \beta_i \log\left(x_i - \gamma_i\right)$$

where x_i is consumption of good i, γ_i is subsistence consumption of good i, $x_i > \gamma_i$, $0 \leq \beta_i \leq 1$, and $\sum_i \beta_i = 1$,

subject to

$$y = \sum_i p_i x_i.$$

This will yield the following demand system in expenditure form, which is called Linear Expenditure System (LES).

$$p_i x_i = p_i \gamma_i + \beta_i \left(y - \sum_j p_j \gamma_j \right)$$

Compared to Cobb-Douglas and CES demand system, LES is richer for distributional effect analysis, because income elasticity is not constant, hence the impact on the same percentage shock on each household income, would generate different behavioral responses by each households. The natural reason that income elasticity of households are different is that marginal utility of income vary with level of income. Poor households will have higher marginal utility of income, while rich household will have lower. In the LES, this is captured by Frisch parameter that varies with income level.

A.3. Model Database and Parameters

The database for the model is built based on the Social Accounting Matrix 2003 specifically constructed for this research, as described in detail in the earlier section. For the purpose of the case studies the industry is aggregated into 38 sectors and the commodity is aggregated into 43 sectors.

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[25] Although in the model, it will only applies to a single refinery industry that allow to produce multiple type of fuels.

There are some sets of parameters of which their values have to be estimated or borrowed from literature or other models. Those set of parameters are: (1) Armington elasticity between domestic and imported commodities; (2) Export elasticity; (3) Elasticity of substitution among labor types (or skills); (4) Elasticity of substitution among primary factors; (5) CET 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.

Parameter 1 to 5 are taken from GTAP database. Parameter 6 and 7 is borrowed from INDOCEEM[26] model. Here, the elasticity of substitution among fossil-fuel energy is set moderately 0.25, while the elasticity of substitution between energy composite and primary factors of production is set to be 0.1. All of the parameters which are borrowed from literature or other model are subject to sensitivity analysis as discussed in the next section.

Expenditure elasticity parameter are estimated econometrically, and Frisch parameter is calculated based on the study by Lluch et al. (1977).

APPENDIX B: SYSTEMATIC 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 respects 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 are examined. However, since there are many parameters are imputed into the model, this approach is difficult or less practical to be implemented 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, the sensitivity analysis to each of the parameters would be computationally burdensome.

Recent advances in the literature on sensitivity analysis offer a rather convenient approach, i.e., systematic sensitivity analysis[27]. The question to be asked in this sensitivity analysis is, how reliable is the results if we vary 'all' the parameters in the model, let's say by 50%. Hence, if for example, the Armington elasticity of commodity A is 5, then we allow it to vary between 2.5 and 7.5. We will do it for all the parameters. The popular approach is a typical Monte Carlo simulation, where we draw independently enough number from each of the range value of the parameters, and do that in a sufficiently large draw such that the result is statistically accurate. However, with this kind of approach, time and computational constraint will prevent the accuracy of the estimates.

The new approach is the so-called Systematic Sensitivity Analysis (SSA) via Gaussian Quadrature. This is a type of programming or optimisation method. Given the distribution of M parameters, what is the best possible choice of parameters in N simulations if we want to estimate means and standard deviations for all endogenous variables. A procedure for choosing the N parameters made in this way is often referred to a Gaussian quadrature. However, this assumes (1) the simulation results are well approximated by a third-order polynomial in the varying parameters; (2) that parameters which vary all have a symmetric distribution[28]; (3) the parameters vary quite independently (zero correlation). Arndt (1996) for example demonstrates that the results are often surprisingly accurate, given the relatively modest number of times the model is solved.

The confidence interval for each endogenous variables is calculated by employing the Chebyshev's

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[26] A model developed by Monash University and Indonesian Ministry of Energy.

[27] See Arndt (1996), Pearson and Arndt (2000), and its implementation among others in Hertel et al. (2003), and Plumb (2001).

[28] The SSA carried out in this paper, the parameters are assumed to have triangular distribution.

inequality. Suppose that we have an endogenous variable y with mean μ and standard deviation σ. Chebyshev's inequality says that, whatever the distribution of the variable in question, for each positive real number k, the probability that the value of y does not lie within k standard deviations of the mean $\mu$is no more than $\frac{1}{k^2}$. The confidence interval is calculated as $\mu \pm k \cdot \sigma$, where $k = 3.16$ for 90% confidence interval, and $k = 4.47$ for the 95%. In this SSA, all parameters are assumed to vary by 50%, and the SSA is implemented in Gempack (Pearson and Arndt, 2000).Table 6 shows the result of systematic sensitivity analysis for carbon tax simulation (SIM 1, no-recycled revenue), assuming triangular distribution in the parameters, with 50% variation from the mean, and applied using Gaussian Quadrature approach. In general, the result suggests, that the result is robust to variation in the extraneous parameters, as shown by low standard deviation of most endogenous variables.

However, some macroeconomic variables tend to be more sensitive to parameters. Statistically speaking, for example, we can not 90% confident, that GDP or aggregate consumption fall, because its upper confidence interval is non-negative. However, CPI is relatively insensitive, but CO_2 emission seems to have very wide confidence interval.

For factor price variables, some real wages such as for agricultural labor are relatively more sensitive, but for real wage of other type of labor is relatively less sensitive to variation in parameters. However, the qualitative direction is robust with even 95% confidence level. Moreover, the pattern on which relative real wage change[29], which has implication in the distributional story, is also robust to sensitivity analysis.

Looking at the confidence interval in real household expenditure by centiles, it also suggests that distributional impact of carbon tax is less likely to be sensitive to parameter variation. It can be interpreted for example, that we are 95% confident that in rural area, real expenditure of the poorest 1% household will rise not less than 1.342%, and that of the richest 1% household will not be better-off (0% rise in expenditure per capita). Therefore, the carbon tax tend to reduce inequality in rural area.

The direction of the poverty impact can also be looked at what happen to households near to the poverty line. In urban area, for example, that household is the centile 13th household. Since its 95% confidence interval is between -0.386 to -0.205, we can be 95% confident that poverty in urban area falls following the introduction of carbon tax.

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[29] For example, the percentage change on the real wage of formal urban production workers, compared to the real wage of informal, rural, agricultural workers.

TABLE 6

SSA of SIM 1: Carbon Tax (50 percent Variation in All Parameters)

			Con. Interval (90%)		Con Interval (95%)	
	mean	s.d.	lower	upper	lower	upper
Macroeconomics						
GDP	-0.040	0.013	-0.081	0.001	-0.098	0.018
Aggregate consumption	-0.061	0.020	-0.122	0.001	-0.148	0.027
CPI	1.324	0.033	1.218	1.430	1.174	1.473
CO2 emission	-6.535	0.656	-8.609	-4.461	-9.468	-3.602
Real wage						
Agriculture, rural, formal	-0.587	0.127	-0.988	-0.187	-1.154	-0.021
Agriculture, urban, formal	-0.548	0.118	-0.922	-0.175	-1.077	-0.020
Agriculture, rural, informal	-0.478	0.120	-0.858	-0.099	-1.015	0.059
Agriculture, urban, informal	-0.497	0.111	-0.849	-0.144	-0.995	0.002
Production, rural, formal	-2.691	0.178	-3.254	-2.128	-3.487	-1.894
Production, urban, formal	-4.647	0.190	-5.248	-4.047	-5.497	-3.798
Production, rural, informal	-2.236	0.195	-2.851	-1.620	-3.106	-1.365
Production, urban, informal	-2.245	0.202	-2.883	-1.606	-3.148	-1.342
Clerical, rural, formal	-2.178	0.069	-2.397	-1.959	-2.487	-1.869
Clerical, urban, formal	-3.126	0.111	-3.479	-2.774	-3.625	-2.628
Clerical, rural, informal	-1.763	0.114	-2.124	-1.402	-2.274	-1.253
Clerical, urban, informal	-1.786	0.112	-2.139	-1.433	-2.285	-1.287
Professional, rural, formal	-3.183	0.134	-3.606	-2.761	-3.781	-2.586
Professional, urban, formal	-3.551	0.115	-3.915	-3.188	-4.065	-3.037
Professional, rural, informal	-2.198	0.184	-2.780	-1.616	-3.021	-1.375
Professional, urban, informal	-2.070	0.114	-2.431	-1.708	-2.581	-1.558
Average price of capital	-4.447	0.082	-4.705	-4.189	-4.813	-4.082
Average price of land	0.919	0.116	0.553	1.284	0.401	1.436
Output						
Coal	-2.933	0.454	-4.370	-1.496	-4.965	-0.901
Natural gas	-0.687	0.139	-1.128	-0.247	-1.310	-0.064
Refinery	-3.837	0.447	-5.252	-2.423	-5.838	-1.837
Electricity	-1.436	0.090	-1.722	-1.151	-1.841	-1.032
Water and gas	-2.238	0.066	-2.448	-2.028	-2.535	-1.941
Road transportation	-0.663	0.077	-0.906	-0.419	-1.007	-0.318
Other transportation	-1.430	0.172	-1.974	-0.885	-2.200	-0.659
Prices						
Coal	131.877	1.574	126.901	136.853	124.840	138.914
Natural gas	26.561	1.542	21.684	31.439	19.663	33.459
Gasoline	24.626	0.294	23.696	25.555	23.311	25.940
Diesel (Automotive)	45.251	0.828	42.634	47.868	41.550	48.952
Diesel (Industries)	43.442	0.786	40.957	45.927	39.928	46.956
Kerosene	29.305	0.534	27.615	30.995	26.915	31.695
LPG	25.714	1.293	21.626	29.802	19.932	31.495
Other fuels	21.389	0.696	19.187	23.591	18.275	24.503
Electricity	16.953	0.852	14.260	19.646	13.144	20.761
Water and gas	12.379	0.295	11.445	13.312	11.058	13.699
Road transportation	1.763	0.060	1.572	1.953	1.493	2.032
Other transportation	2.349	0.072	2.121	2.578	2.027	2.672
Real consumption						
Urban						
Centile 1	0.135	0.031	0.036	0.234	-0.005	0.275
Centile 2	0.083	0.031	-0.014	0.180	-0.054	0.220
Centile 3	0.060	0.030	-0.034	0.154	-0.072	0.193
Centile 4	-0.306	0.031	-0.403	-0.209	-0.443	-0.168
Centile 5	-0.514	0.039	-0.636	-0.393	-0.687	-0.342
Centile 13	-0.296	0.029	-0.386	-0.205	-0.423	-0.168
Centile 95	-0.247	0.028	-0.335	-0.159	-0.372	-0.123
Centile 96	-0.407	0.024	-0.482	-0.333	-0.513	-0.302
Centile 97	-0.223	0.026	-0.305	-0.141	-0.339	-0.107
Centile 98	-0.569	0.022	-0.640	-0.499	-0.669	-0.470
Centile 99	-0.509	0.020	-0.571	-0.447	-0.597	-0.421
Centile 100	-0.343	0.026	-0.424	-0.262	-0.458	-0.229
Rural						
Centile 1	1.657	0.070	1.434	1.880	1.342	1.972
Centile 2	1.546	0.068	1.331	1.760	1.242	1.849
Centile 3	1.625	0.077	1.381	1.869	1.280	1.970
Centile 4	1.711	0.063	1.511	1.911	1.428	1.994
Centile 5	1.453	0.063	1.254	1.652	1.171	1.735
Centile 20	1.157	0.058	0.974	1.339	0.899	1.415
Centile 95	0.002	0.040	-0.124	0.127	-0.176	0.179
Centile 96	-0.228	0.038	-0.347	-0.108	-0.396	-0.059
Centile 97	-0.251	0.035	-0.362	-0.139	-0.408	-0.093
Centile 98	-0.123	0.040	-0.250	0.004	-0.302	0.056
Centile 99	-0.049	0.049	-0.203	0.105	-0.267	0.169
Centile 100	-0.224	0.050	-0.383	-0.066	-0.448	0.000