Working Paper
in Economics and
Development Studies

Department of Economics
Padjadjaran University

No. 202201

Inter-Regional System of Analysis for East Asia: A Manual

Yuventus Effendi
Budy P. Resosudarmo

Australian National University

October, 2022

Center for Economics and Development Studies,
Department of Economics, Padjadjaran University
Jalan Hayam Wuruk No. 6, Bandung, Indonesia.
Phone/Fax: +62-22-4204510
http://www.ceds.feb.unpad.ac.id

Inter-Regional System of Analysis for East Asia: A Manual

By:

Yuventus Effendi and Budy P. Resosudarmo

ABSTRACT

This paper provides detail of the inter-regional system of analysis of East Asia (IRSA-EA). IRSA-EA is a static and multi-country computable general equilibrium (CGE) model. IRSA-EA has a flexible production structure that allows substitutions among electricity and energy intermediate inputs. Hence, the model can simulate the impacts of changes in energy and electricity prices. Also, the model incorporates several recycling mechanisms to simulate the impacts of renewable electricity development and decarbonisation in the East Asia region. This paper provides a technical guide for the IRSA-EA model that will be useful to analyse the socio-economic and environmental impacts of policy instruments in the subsequent two papers.

Keywords: Climate change, computable general equilibrium model, East Asian economy

INTRODUCTION

This paper is a technical paper on constructing an inter-regional system of analysis of East Asia (IRSA-EA). This paper has two-fold objectives. First, this paper aims to provide details of the IRSA-EA model to be used for future replication and expansion. Second, this paper describes the extension of the IRSA-EA model, namely the closed-loop IRSA-EA. The closed-loop IRSA-EA incorporates feedback between climate change and the economy in each East Asian country.

This paper consists of three sections. The first section explains the implementation of a computable general equilibrium model as a tool for policy analysis. Then, the next section overviews the IRSA-EA model, followed by a technical detail with a description of each equation in the model. The final section describes the extension of IRSA-EA by incorporating a feedback mechanism between climate change and the economy.

COMPUTABLE GENERAL EQUILIBRIUM MODEL AS A TOOL OF ANALYSIS

Computable general equilibrium (CGE) or applied general equilibrium (AGE) is a long-standing method to assess the impacts of policy and other shocks in the areas of trade, public finance, labour markets, environment, and financial crises (Dixon and Jorgenson 1997). The first CGE model is conducted in work by Johansen (1960) on the multi-sectoral model of Norway. The distinct feature of this model is explicit institutional behaviour. For example, the household maximises utility to their budget constraint, and firms choose the input that minimises their cost to produce a certain level of output to satisfy demand (Johansen 1960). Another type of CGE model is constructed by Harberger (1962). The Harberger model is used to analyse the effects of corporate income tax in the United States. The model consists of two sectors (corporate and non-corporate sectors) and two production factors (capital and labour) and assumes that the corporate sector pays income tax due to capital earnings.

By the 1980s, there are at least four mainstreams of CGE modelling. First, the Multi-sectoral Growth (MSG) model for Norway is an extension of the Johansen model (Longva, Lorentsen, and Oystein 1985). Second, the ORANI model for Australia is also constructed based on the Johansen model (Dixon, Parmenter, and Powell 1983). Third, a non-linear and at level CGE model by Adelman and Robinson (1978) for the Korean economy. Finally, there is a work by Shoven and Whalley (1972) for the United States that is an extension of the Harberger model.

Since then, CGE studies cover a wide range of topics. Among others, CGE modelling is used for the analysis of shocks in public finance (Ballard et al. 1985); income distribution (Adelman and Robinson 1988); air pollutant and economy (Resosudarmo and Thorbecke 1996); financial crises (Adelman and Yeldan 2000); climate change (Ciarli and Savona 2019); and fiscal stimulus impacts (Resosudarmo et al. 2021).

There are two types of CGE models based on the geographical coverage area: single country and multi-country. A single country CGE model focuses on a specific geographical area. This single country CGE model has highly disaggregated sectors, disaggregated factor incomes, and disaggregated institutional. There are many single-country CGE model has been constructed for each East Asian country. For Indonesia, early work by (Lewis 1991) analyse deregulation policy in Indonesia; a work Thorbecke (1991) integrates real sector and financial sector in a CGE model for Indonesia; the impact of Asian financial crisis in Indonesia (Azis 2000); the impacts of air pollutants on the economy in Indonesia (Resosudarmo 2002), the distributive impact of a carbon tax in Indonesia (Yusuf and Resosudarmo 2015), and fiscal stimulus impacts in Indonesia (Resosudarmo et al. 2021).

CGE models of other East Asian countries include, among others, the ORANI model for Australia by Dixon, Parmenter, and Powell (1983) and MONASH model is an extension of the ORANI-F model (Adams et al. 1994); an adaptation of ORANI for China (Martin 1993); Japan by

Shishido (1982); BMW model in India (Becker, Mills, and Williamson 1986); South Korea by Hamilton (1986); a competitive market CGE in Malaysia by Lundborg (1984); adaptation of the Johansen model in the Philippines (Coxhead and Warr 1991); a simple general equilibrium model (Kapur 1983) and adaptation of GTAP model in Singapore (Siriwardana and Iddamalgoda 2003), SIAM1 model for Thailand (Drud and Grais 1983); Vietnam Agricultural Spatial-Equilibrium Model in Vietnam (Minot and Goletti 1998) and AGE model for managing commercial forestry in Vietnam (Dufournaud et al. 2000); Brunei by Duraman and Asafu-Adjaye (1999); M-SGEM model for Lao (Warr, Menon, and Yusuf 2010); adaptation of GTAP in Cambodia and Myanmar (Yang et al. 2009).

Relatively different to the single country model, a multi-country CGE model focuses on a broader geographical area, i.e., two or more countries. The multi-country model examines the cross-border transactions among countries, such as the movement of goods, people, and production factors. The early work on the multi-country CGE model can be found in the work by Whalley (1985) that examines the trade liberalisation in seven European countries, the US, Japan, and developing countries. Similarly, the Michigan Model of World Production and Trade by Deardorff and Stern (1986) covers 34 countries to examine the impacts of the Tokyo round of multilateral trade liberalisation.

One of the probably most used multi-country CGE models in recent years is the Global Trade Analysis Project (GTAP) model. GTAP model rests on input-output accounting framework, is a multi-country and multi-sector model and a comparative static model (Corong et al. 2017). The main data source of the GTAP model is the GTAP database. The current GTAP database, GTAP 10, covers 141 countries, 65 sectors (Aguiar et al. 2019).

Some multi-country CGE models are used the GTAP database to calibrate their model. This type of multi-country model has a structure that relatively different to the GTAP model. For example, there is the Globe model, a multi-country and SAM based global CGE model (McDonald, Thierfelder, and Robinson 2007). The main feature of the Globe model is a dummy region, named globe, that allows inter-regional transaction recording. Another global model that used the GTAP database is the LINKAGE model. LINKAGE, developed by the World Bank, is a multi-region, multi-sector, and dynamic CGE model (Van Der Mensbrugghe 2005). For the Southeast Asia region, an inter-regional system of analysis for ASEAN (IRSA-ASEAN) model by Nurdianto (2011) uses the GTAP database as a primary data source to construct its own inter-regional SAM.

OVERVIEW OF IRSA-EA MODEL

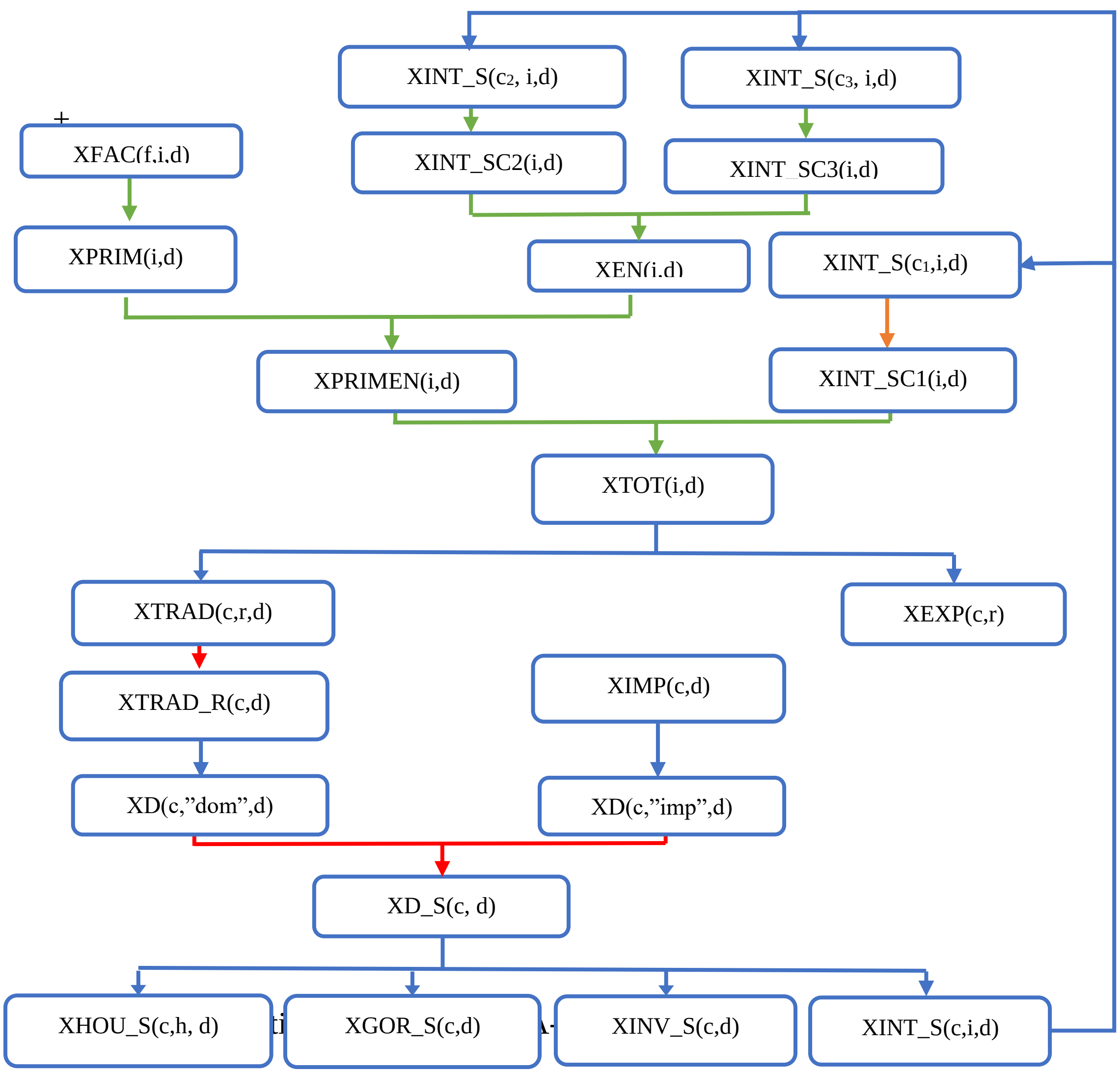
The IRSA-EA model is a static and multi-country CGE model. The optimisation in the IRSA-EA model is solved at the country level. This approach implies that price and quantities vary independently by country. In other words, the model observes the changes in price and quantity in each country.

Several features of IRSA-EA come from developments in CGE modelling that have been made over many years. For example, the features of IRSA-EA are build based on studies by Dervis, de Melo and Robinson (1982), Adelman and Robinson (1988), Thorbecke (1991), and Resosudarmo (2002). The multi-region CGE features in the IRSA-EA can be traced back to early work at the global level by Adelman and Yeldan (2000), in Indonesia by Tokunaga et al. (2003) and Resosudarmo et al. (1999), and in South Korea (Kim and Kim 2002).

IRSA-EA is a direct descendant of the inter-regional system of analysis for the ASEAN (IRSA-ASEAN) model by Nurdianto (2011) and the inter-regional system of analysis for Indonesia five regions (IRSA-Indonesia5) developed by Resosudarmo et al. (2011). Therefore, IRSA-EA has similarities in terms of notational use and purposes with IRSA-ASEAN and IRSA-Indonesia5.

There are two significant expansions of the IRSAM-EA that make it distinguishable from both IRSA-Indonesia5 and IRSA-ASEAN: a flexible production structure and specific recycling mechanisms for simulating renewable electricity development, i.e., indirect tax reduction of renewable electricity sectors and subsidies for households to consume more renewable electricity.

Figure 1. Flow-chart of IRSA-EA



Subscript notations in Figure 1 are defined as follows
c commodity;

CES
Leontief
Armington

c_1 non-energy and non-electricity intermediate inputs;
c_2 energy intermediate inputs (coal, gas, petroleum products, gas manufacture distribution);
c_3 electricity intermediate inputs (wind, hydro, solar, coal electricity, oil electricity, gas electricity, other electricity);
d country destination of commodity;
f production factor;
h household;
i industry;
r country source of commodity;
s source of commodity, composite between domestic (”dom”) and import (”imp”).

The first expansion of IRSA-EA is a flexible production structure. A flexible production structure of IRSA-EA allows for substitutions between primary and intermediate energy and electricity inputs. Allowing a flexible substitution among energy and electricity intermediate inputs enables the model to simulate the impacts of the lower price of particular commodities such as renewable electricity to the whole economy (Yusuf and Resosudarmo 2015).

Figure 1 describes the nested production structure of IRSA-EA as a flow of supply and demand of industry i in country d. On the demand side, $XTOT(i,d)$ denotes output produced by sector i in region d through four levels of aggregation of constant elasticity substitution (CES) functions:

- At the bottom level, demand for intermediate energy $XINT\_S(c2,i,d)$ and intermediate electricity inputs $XINT\_S(c3,i,d)$ are CES aggregated into composite energy intermediate inputs $XINT\_SC2(i,d)$ and composite electricity intermediate inputs $XINT\_SC3(i,d)$.
- At the third level, both $XINT\_SC2(i,d)$ and $XINT\_SC3(i,d)$ are CES aggregated into a composite of energy and electricity intermediate inputs $XEN(i,d)$. At the same production level, production factors $XFAC(f,i,d)$ are CES aggregated into a composite of primary inputs $XPRIM(i,d)$.
- At the second level, $XEN(i,d)$ and $XPRIM(i,d)$ are CES aggregated into a composite of primary-energy-electricity inputs $XPRIMEN(i,d)$. At the same level, non-energy and non-electricity intermediate inputs $XINT\_S(c1,i,d)$ are Leontief aggregated into a composite of non-energy and non-electricity intermediate inputs $XINT\_SC1(i,d)$.
- Finally, on the top nest level, both $XPRIMEN(i,d)$ and $XINT\_SC1(i,d)$ are CES aggregated into $XTOT(i,d)$.

The output of $XTOT(i,d)$ is then supplied into the domestic market $XTRAD(c,r,d)$ and export market $XEXP(c,r)$. Country of destination d of commodity c chooses optimal demand from different origin countries r in aggregated CES function. Similarly, country d also chooses the optimal condition between domestic $XD(c,'dom',d)$ and import $XD(c,'imp',d)$ goods using the Armington assumption. Finally, the optimal $XD\_S(c,d)$ supplies the final demand in country d that comes from households $XHOU\_S(c,h,d)$, government $XGOR\_S(c,d)$, investment $XINV\_S(c,d)$, and intermediate inputs $XINT\_S(c,i,d)$. The optimisation of the final demand of households and government is done with a constant budget share.

CONSTRUCTION OF IRSA-EA MODEL

The main principle of the production activity in Figure 1 is to transform inputs into outputs. In the IRSA-EA model, the relationships of inputs and outputs are represented by the nested CES-Leontief production function for each sector. CES nested production function allows the production function to be more sensitive to price changes. In this case, across sectors have similar production functions, four levels of production functions as presented in the previous section.

There are two main inputs: primary and intermediate inputs consisting of three types of composite intermediate inputs: electricity, energy, and non-electricity and non-energy intermediate inputs. The source of composite primary inputs comes from the domestic market only, while composite intermediate inputs can come from domestically produced intermediate inputs and imported intermediate inputs.

Production of Composite Intermediate Inputs

At the first stage, a firm maximises profit through a CES production function of composite intermediate inputs. There are two composite intermediate inputs at this stage: energy intermediate inputs and electricity intermediate inputs. The optimisation problem for intermediate energy inputs as follows:

$$min_{\{XINT\_S_{c2,i,d}\}}\, f(XINT\_S_{c2,i,d})\ s.t. XINT\_SC2_{i,d}\ = CES[XINT\_S_{c2,i,d}|\sigma_i^{eny}] \quad (1)$$

with

$$f\big(XINT\_S_{c2,i,d}\big) = \sum_{c2}(PQ\_S_{c2,d}\ .XINT\_S_{c2,i,d}) \quad (2)$$

where $PQ\_S_{c2,d}$ is intermediate input price for energy, $XINT\_S_{c2,i,d}$ is demand for intermediate energy input, $XINT\_SC2_{i,d}$ is the composite of intermediate energy input, and $CES[XINT\_S_{c2,i,d}|\sigma_i^{eny}]$ is a CES functional form that represents the relationship amongst the intermediate energy inputs. σ_i^{eny} is the elasticity of substitution for each industry i.

The solution of Equation (1), following Resosudarmo et al.(2008) as follows:

$$\mathrm{XINT\_S}_{c2,i,d} = \alpha_{\mathrm{i,d}}^{\mathrm{eny}\frac{-\rho^{eny}}{\rho^{eny}+1}}.\mathrm{XINT\_SC2_{i,d}}.\delta_{\mathrm{c2,i,d}}^{\mathrm{eny}\ \frac{1}{\rho^{eny}+1}}.\left(\frac{\mathrm{PQ\_S_{c2,d}}}{\mathrm{PQ\_SC2_{i,d}}}\right)^{\frac{-1}{\rho^{eny}+1}} \quad (3)$$

Where $PQ\_SC2_{i,d}$ is the price of composite energy intermediate inputs paid by industry i in destination country d, $\alpha_{i,d}^{eny}$ is the shift parameter of intermediate energy inputs, $\delta_{f,i,d}^{eny}$ is the shared parameter of intermediate energy inputs, and ρ^{eny} denotes $\rho_{i,d}^{eny}$ is a parameter of composite energy intermediate inputs derived from the elasticity of substitution σ_i^{eny}.

The market-clearing for the intermediate energy inputs is as follows:

$$\mathrm{PQ\_SC2_{i,d}.XINT\_SC2_{i,d}} = \sum_{\mathrm{c2}}(1+\mathrm{stx_{c2,d}})\,.\mathrm{PQ\_S_{c2,d}.XINT\_S_{c2,i,d}} \quad (4)$$

Where $\mathrm{stx}_{\mathrm{c2,d}}$ is the sales tax rate for a commodity if there exists a carbon tax. The sales tax rate is an empty set if there is no carbon tax policy.

Similarly, for composite electricity intermediate inputs, the optimisation problem is as follow:

$$min_{\{XINT\_S_{c3,i,d}\}} f(XINT\_S_{c3,i,d})\ s.t.XINT\_SC3_{i,d} = CES[XINT\_S_{c3,i,d}|\sigma_i^{ely}] \quad (5)$$

with

$$f(XINT\_S_{c3,i,d}) = \sum_{c3}(PQ\_S_{c3,d}\ .XINT\_S_{c3,i,d}) \quad (6)$$

where $PQ\_S_{c3,d}$ is intermediate input price for electricity, $XINT\_S_{c3,i,d}$ is demand for intermediate electricity input, $XINT\_SC3_{i,d}$ is the composite of intermediate electricity input, and $CES[XINT\_S_{c3,i,d}|\sigma_i^{ely}]$ is a CES functional form that represents the relationship amongst the intermediate electricity inputs. σ_i^{ely} is the elasticity of substitution for each industry i.

The solution of Equation (5), following Resosudarmo et al.(2008) as follows:

$$\mathrm{XINT\_S_{c3,i,d}} = \alpha_{\mathrm{i,d}}^{\mathrm{ely}\frac{-\rho^{ely}}{\rho^{ely}+1}}.\mathrm{XINT\_SC3_{i,d}}.\delta_{\mathrm{c3,i,d}}^{\mathrm{ely}\frac{1}{\rho^{ely}+1}}.\left(\frac{\mathrm{PQ\_S_{c3,d}}}{\mathrm{PQ\_SC3_{i,d}}}\right)^{\frac{-1}{\rho^{ely}+1}} \quad (7)$$

Where $PQ\_SC3_{i,d}$ is the price of composite electricity intermediate inputs paid by industry i in destination country d, $\alpha_{i,d}^{ely}$ is the shift parameter of intermediate electricity inputs, $\delta_{f,i,d}^{ely}$ is the shared parameter of intermediate electricity inputs, and ρ^{ely} denotes $\rho_{i,d}^{ely}$ is a parameter of composite electricity intermediate inputs derived from the elasticity of substitution σ_i^{ely} .

The market-clearing for the intermediate electricity inputs is as follows:

$$\mathrm{PQ\_SC3_{i,d}}.\mathrm{XINT\_SC3_{i,d}} = \sum_{\mathrm{c3}}(1+\mathrm{stx_{c3,d}})\ .\mathrm{PQ\_S_{c3,d}}.\mathrm{XINT\_S_{c3,i,d}} \quad (8)$$

Where $\mathrm{stx_{c3,d}}$ is the sales tax rate for a commodity if there exists a carbon tax. The sales tax rate is an empty set if there is no carbon tax policy.

Demand for primary factors

At the second stage, the firm optimises demand for primary factors. The optimisation problem for primary factors as follows:

$$min_{\{XFAC_{f,i,d}\}} f(XFAC_{f,i,d})\ s.t. XPRIM_{i,d} = CES[XFAC_{f,i,d}|\sigma_i^{prim}] \quad (9)$$

with

$$f(XFAC_{f,i,d}) = \sum_f (PFAC_{f,d}\ .XFAC_{f,i,d}) \quad (10)$$

where $PFAC_{f,d}$ is factor price, $XFAC_{f,i,d}$ is demand for primary factor f, $XPRIM_{i,d}$ is the composite of primary factors, and $CES[XFAC_{f,i,d}|\sigma_i]$ is a CES functional form that represents the relationship amongst the primary factors. σ_i^{prim} is the elasticity of substitution for each industry i. The solution of Equation (9), following Resosudarmo et al.(2008) as follows:

$$\mathrm{XFAC_{f,i,d}} = \alpha_{\mathrm{i,d}}^{\mathrm{prim}\frac{-\rho^{prim}}{\rho^{prim}+1}}.\mathrm{XPRIM_{i,d}}.\ \delta_{\mathrm{f,i,d}}^{\mathrm{prim}\frac{1}{\rho^{prim}+1}}.\left(\frac{\mathrm{PFAC_{f,d}}}{\mathrm{PPRIM_{i,d}}}\right)^{\frac{-1}{\rho^{prim}+1}} \quad (11)$$

Where $PPRIM_{i,d}$ is the price of composite primary factors paid by industry i in destination country d, $\alpha_{\mathrm{i,d}}^{\mathrm{prim}}$ is the shift parameter of value-added, $\delta_{f,i,d}$ is the shared parameter of value-added, and ρ^{prim} denotes $\rho_{i,d}^{prim}$ is a parameter of value-added derived from the elasticity of substitution σ_i^{prim}.

The market-clearing for the primary factors is as follows:

$$\sum_i XFAC_{f,i,d} + XFACRO_{f,d} = \sum_h \sum_r XFACS_{r,h,d,f} + \sum_r XFGR_{r,d,f} + \sum_r XFCO_{r,d,f} + XFRO_{d,f} \quad (12)$$

where $XFACRO_{f,d}$ is the demand for factors by the rest of the world, $XFACS_{r,h,d,f}$ is the supply of factors by households, $XFGR_{r,d,f}$ is the supply of factors by governments, $XFCO_{r,d,f}$ is the supply of factors by corporate, $XFRO_{d,f}$ is the supply of factors by the rest of the world. Variables on the left-hand side are treated as exogenous in the model.

5.1.1.

Demand for composite energy and electricity intermediate inputs

Similarly, at the second stage, the firm optimises demand for the composite of energy and electricity intermediate inputs. The optimisation problem for the composite of energy and electricity intermediate inputs as follows:

$$min_{\{XINT\_SC2_{i,d},XINT\_SC3_{i,d}\}} f\left(XINT\_SC2_{i,d}, XINT\_SC3_{i,d}\right)$$
$$s.t. XEN_{i,d} = CES\left[XINT\_SC2_{i,d}, XINT\_SC3_{i,d} \middle| \sigma_i^{en}\right] \quad (13)$$

with

$$f\left(XINT\_SC2_{i,d}, XINT\_SC3_{i,d}\right) = PQ\_SC2_{i,d}.XINT\_SC2_{i,d} + PQ\_SC3_{i,d}.XINT\_SC3_{i,d} \quad (14)$$

where $PQ\_SC2_{i,d}$ is the price of composite energy intermediate inputs, $XINT\_SC2_{i,d}$ is demand for composite energy intermediate inputs c2. Similarly, $PQ\_SC3_{i,d}$ is the price of composite electricity intermediate inputs, $XINT\_SC3_{i,d}$ is demand for composite electricity intermediate inputs c3. $XEN_{i,d}$ is the composite of energy and electricity intermediate inputs, and $CES\left[XINT\_SC2_{i,d}, XINT\_SC3_{i,d} \middle| \sigma_i^{EN}\right]$ is a CES functional form that represents the relationship amongst the composites of energy and electricity intermediate inputs. σ_i^{EN} is the elasticity of substitution between composites of energy and electricity intermediate inputs.

The solution of Equation (13) as follows:

$$\mathrm{XINT\_SC2_{i,d}} = \alpha_{\mathrm{i,d}}^{\mathrm{en}\frac{-\rho^{en}}{\rho^{en}+1}}.\mathrm{XEN_{i,d}}.\delta_{\mathrm{i,d}}^{\mathrm{en}\frac{1}{\rho^{en}+1}}.\left(\frac{\mathrm{PQ\_SC2_{i,d}}}{\mathrm{PEN_{i,d}}}\right)^{\frac{-1}{\rho^{en}+1}} \quad (15)$$

$$\mathrm{XINT\_SC3_{i,d}} = \alpha_{i,d}^{en\frac{-\rho^{en}}{\rho^{en}+1}}.\mathrm{XEN_{i,d}}.(1 - \delta_{i,d}^{en})^{\frac{1}{\rho^{en}+1}}.\left(\frac{\mathrm{PQ\_SC3_{i,d}}}{\mathrm{PEN_{i,d}}}\right)^{\frac{-1}{\rho^{en}+1}} \quad (16)$$

Where $PEN_{i,d}$ is the price of composite energy and electricity intermediate inputs paid by industry i in destination country d, $\alpha_{i,d}^{en}$ is the shift parameter of value-added, $\delta_{i,d}^{en}$ is the shared parameter of composite energy and electricity intermediate inputs, and ρ^{en} denotes $\rho_{i,d}^{en}$ is a parameter of composite energy and electricity intermediate inputs derived from the elasticity of substitution σ_i^{en}.

The market-clearing for the composite energy and electricity intermediate inputs is as follows:

$$PEN_{i,d}.XEN_{i,d} = PQ\_SC2_{i,d}.XINT\_SC2_{i,d} + PQ\_SC3_{i,d}.XINT\_SC3_{i,d} \quad (17)$$

Demand for composite primary factors-energy-electricity intermediate inputs

At the third stage, the firm optimises demand between the composite of primary and of energy-electricity intermediate inputs. The optimisation problem for the composite of primary and energy-electricity intermediate inputs as follows:

$$min_{\{XPRIM_{i,d},XEN_{i,d}\}} f(XPRIM_{i,d}, XEN_{i,d})$$

$$s.t.XPRIMEN_{i,d} = CES[XPRIM_{i,d}, XEN_{i,d} | \sigma_i^{primen}] \quad (18)$$

with

$$f(XPRIM_{i,d}, XEN_{i,d}) = PPRIM_{i,d}.XPRIM_{i,d} + PEN_{i,d}.XEN_{i,d} \quad (19)$$

where $XPRIMEN_{i,d}$ is the composite of primary and energy- electricity intermediate inputs, and $CES[XPRIM_{i,d}, XEN_{i,d} | \sigma_i^{primen}]$ is a CES functional form that represents the relationship amongst the composites of primary and energy-electricity intermediate inputs. σ_i^{primen} is the elasticity of substitution between composites of primary and energy-electricity intermediate inputs.

The solution of Equation (18) as follows:

$$\mathrm{XPRIM_{i,d}} = \alpha_{i,d}^{\mathrm{primen}\frac{-\rho^{primen}}{\rho^{primen}+1}}.\mathrm{XPRIMEN_{i,d}}.\delta_{i,d}^{\mathrm{primen}\frac{1}{\rho^{primen}+1}}.\left(\frac{\mathrm{PPRIM_{i,d}}}{\mathrm{PPRIMEN_{i,d}}}\right)^{\frac{-1}{\rho^{primen}+1}} \quad (20)$$

$$\mathrm{XEN_{i,d}} = \alpha_{i,d}^{\mathrm{primen}\frac{-\rho^{primen}}{\rho^{primen}+1}}.\mathrm{XPRIMEN_{i,d}}.(1 - \delta_{i,d}^{\mathrm{primen}})^{\frac{1}{\rho^{primen}+1}}.\left(\frac{\mathrm{PEN_{i,d}}}{\mathrm{PPRIMEN_{i,d}}}\right)^{\frac{-1}{\rho^{primen}+1}} \quad (21)$$

Where $PPRIMEN_{i,d}$ is the price of the composite of primary and energy- electricity intermediate inputs paid by industry i in destination country d, $\alpha_{i,d}^{primen}$is the shift parameter of the composite of primary and energy- electricity intermediate inputs, $\delta_{i,d}^{primen}$ is the shared parameter of the composite of primary and energy- electricity intermediate inputs, and ρ^{primen} denotes $\rho_{i,d}^{primen}$ is a parameter of the composite of primary and energy-electricity intermediate inputs derived from the elasticity of substitution σ_i^{primen}.

The market-clearing for the composite of primary and energy-electricity intermediate inputs is as follows:

$$PPRIMEN_{i,d}.XPRIMEN_{i,d} = PPRIM_{i,d}.XPRIM_{i,d} + PEN_{i,d}.XEN_{i,d} \quad (22)$$

Demand for composite non-energy and non-electricity intermediate inputs

At the third stage, the firm also has the composite of non-energy and non-electricity intermediate inputs as a Leontief production function as a proxy of a fixed share of inputs as follow:

$$XINT\_S_{c1,i,d} = \alpha_{c1,i,d}^{int}.XINT\_SC1_{i,d} \quad (23)$$

Where $XINT\_S_{c1,i,d}$ is non-energy and non-electricity intermediate inputs, $\alpha_{c1,i,d}^{int}$ is the proportion of non-energy and non-electricity intermediate inputs of the composite level of non-energy and non-electricity intermediate inputs $XINT\_SC1_{i,d}$.

The market-clearing for the composite of non-energy and non-electricity intermediate inputs is as follows:

$$PQ\_SC1_{i,d}.XINT\_SC1_{i,d} = \sum_{C1}(1 + stx_{c,d})\, PQ\_S_{c1}.XINT\_S_{c1,i,d} \qquad (24)$$

Where $PQ\_SC1_{i,d}$ is the price of composite non-energy non-electricity intermediate inputs paid by industry i in destination country d, $stx_{c,d}$ is the sales tax rate if there exists a carbon tax. The sales tax rate is an empty set if there is no carbon tax policy. PQ_S_{c1} is the price of commodities c.

Production of output

At the fourth stage, the firm optimises its profit through a CES production function between the composite of non-energy and non-electricity intermediate inputs and the composite of primary and energy- electricity intermediate inputs as follow:

$$\mathrm{XTOT_{i,d}} = \alpha^{\mathrm{tot}}_{\mathrm{i,d}}.\left(\delta^{\mathrm{tot}}_{\mathrm{i,d}}.\mathrm{XINT\_SC1_{i,d}}^{-\rho^{tot}} + \left(1 - \delta^{\mathrm{tot}}_{\mathrm{i,d}}\right).\mathrm{XPRIMEN_{i,d}}^{-\rho^{tot}}\right)^{-\frac{1}{\rho^{tot}}} \qquad (25)$$

Where $XTOT_{i,d}$ denotes the level of output of industry i at country d, $\alpha_{i,d}^{tot}$ is the shift parameter of CES production function between the composite of non-energy and non-electricity and the composite of energy-electricity intermediate inputs, $\delta_{i,d}^{tot}$ is the shared parameter of the composite of non-energy and non-electricity and composite of energy-electricity intermediate inputs, and ρ^{tot} denotes $\rho_{i,d}^{tot}$ is a parameter of the composite of primary and energy-electricity intermediate inputs derived from the elasticity of substitution σ_i^{tot}.

At the first-order condition, the marginal revenue of producing the commodity is equal to the marginal cost. Therefore, the first-order condition of Equation (25) is as follow:

$$\frac{\mathrm{XINT\_SC1_{i,d}}}{\mathrm{XPRIMEN_{i,d}}} = \left(\frac{\mathrm{PPRIMEN_{i,d}}}{\mathrm{PQ\_SC1_{i,d}}}.\frac{\delta^{\mathrm{tot}}_{\mathrm{i,d}}}{(1 - \delta^{\mathrm{tot}}_{\mathrm{i,d}})}\right)^{\frac{1}{1+\rho^{tot}}} \qquad (26)$$

The zero-profit condition for the top-level production function is as follows:

$$(1 - itxr_{i,d} + ritxr_{i,d})\ PDOM_{i,d}.XTOT_{i,d}$$

$$= PPRIMEN_{i,d}.XPRIMEN_{i,d} + PQ\_SC1_{i,d}.XINT\_SC1_{i,d} \qquad (27)$$

Where $itxr_{i,d}$ is the indirect tax rate, $ritxr_{i,d}$ is indirect tax reduction rate recycled from energy subsidy reduction or carbon tax revenue. In the absence of carbon tax revenue, $ritxr_{i,d}$ is equal to zero. The output of industry c in country r is then distributed to the domestic ($XTRAD_{c,r,d}$) and foreign markets ($XEXP_{c,r}$).

$$XTOT_{c,r} = \left(\sum_{d} XTRAD_{c,r,d}\right) + XEXP_{c,r} \qquad (28)$$

Inter-regional trade and import

Bear in mind that the East Asia model assumes there are two types of trade, inter-regional trade and intra-regional trade. Inter-regional trade is a trade amongst East Asia countries, while intra-regional trade is trade with the rest of the world. Therefore, the demand of commodity c with source country r to country d is optimised, minimising the cost subject to a CES aggregation function as follow:

$$min_{\{XTRAD_{c,r,d}\}}\ f\left(XTRAD_{c,r,d}\right)\ s.t.XTRAD\_R_{c,d} = CES\left[XTRAD_{c,r,d}\middle|\sigma_{c,d}^{trad}\right] \qquad (29)$$

with

$$f\left(XTRAD_{c,r,d}\right) = \sum_{r}[(1 - itxm_{c,r,d})\ .PDOM_{c,d}.XTRAD_{c,r,d}] \qquad (30)$$

where $XTRAD_{c,r,d}$ is the demand of commodity c from source country r in-country d, $itxm_{c,r,d}$ is import tariff of commodity c from source country r in country d, $PDOM_{c,d}$ is the producer price of commodity c at destination country d, $XTRAD\_R_{c,d}$ is composite demand of commodity c in country d, $CES\left[XTRAD_{c,r,d}\middle|\sigma_{c,d}^{trad}\right]$ is a CES functional form that represents the demand of commodity c from all source countries to country destination d, $\sigma_{c,d}^{trad}$ is the elasticity of substitution of commodity c from a different source country r at a country destination d.

The solution of Equation (30) as follows:

$$\mathrm{XTRAD_{c,r,d}} = \alpha_{c,d}^{trad\frac{-\rho^{trad}}{\rho^{trad}+1}}.\mathrm{XTRAD_{R_{c,d}}}.\delta_{c,r,d}^{trad\frac{1}{\rho^{trad}+1}}.\left(\frac{(1-\mathrm{itxm_{c,r,d}}).\mathrm{PDOM_{c,d}}}{\mathrm{PQ_{c,"dom",d}}}\right)^{\frac{-1}{\rho^{trad}+1}} \quad (31)$$

Where $PQ_{c,“dom”,d}$ is the domestic purchaser's price for commodity c in country d, $\alpha_{c,d}^{trad}$is the shift parameter for commodity c in country d, $\delta_{c,r,d}^{trad}$ is the share parameter of commodity c from source country r in country d, and ρ^{trad} denotes $\rho_{c,d}^{trad}$ is a parameter of commodity c from source country r in country d derived from the elasticity of substitution $\sigma_{c,d}^{trad}$.

Demand for commodities

The inter-regional trade within East Asia is identical to $XTRAD\_R_{c,d}$, such that

$$XTRAD\_R_{c,d} = XD_{c,“dom”,d} \quad (32)$$

while intra-regional trade such as imports from the rest of the world is as follow:

$$XIMP_{c,d} = XD_{c,“imp”,d} \quad (33)$$

where $XIMP_{c,d}$ is the demand of commodity c from outside of East Asia countries to destination country d. Then, $XD_{c,“imp”,d}$ and $XD_{c,“dom”,d}$ are combined using CES function as follow:

$$min_{\{XD_{c,s,d}\}}\, f(XD_{c,s,d})\ s.t.XD\_S_{c,d} = CES\left[XD_{c,s,d}\middle|\sigma_{s,d}^{arm}\right] \quad (34)$$

with

$$f(XD_{c,s,d}) = \sum_{s}[\,PQ_{c,s,d}.XD_{c,s,d}] \quad (35)$$

The solution of Equation (34) as follows:

$$XD_{c,s,d} = \alpha_{c,d}^{arm \frac{-\rho^{arm}}{\rho^{arm}+1}} . XD\_S_{c,d} . \delta_{c,s,d}^{arm \frac{1}{\rho^{arm}+1}} . \left(\frac{PQ_{c,s,d}}{PQ\_S_{c,d}}\right)^{\frac{-1}{\rho^{arm}+1}} \quad (36)$$

Where $XD\_S_{c,d}$ is the demand for commodity c from composite sources, imported from inside and outside East Asia region, at destination country d. $PQ_{c,s,d}$ is the purchaser's price of commodity c from source country s at destination country d and $PQ\_S_{c,d}$ is the purchaser's price of commodity c from composite sources at destination country d.

In the equilibrium, the total demand of commodity c in country d ($XD_{c,s,d}$) should be equal to the final demand from the household $\left(\sum_h XHOUS\_S_{c,h,d}\right)$, government ($XGOR\_S_{c,d}$), investment ($XINV\_S_{c,d}$), and intermediate inputs $\left(\sum_i XINT\_S_{c,i,d}\right)$ as follow:

$$XD\_S_{c,d} = \sum_i XINT\_S_{c,i,d} + \sum_h XHOUS\_S_{c,h,d} + XGOR\_S_{c,d} + XINV\_S_{c,d} \quad (37)$$

Household optimisation

The household maximises its utility as follow:

$$max_{XHOU\_S_{c,h,d}} U_{h,d} = f\left(XHOU\_S_{c,h,d}\right)$$

$$s.t. EH_{h,d} = \sum_c [(1 + stx_{c,d}).(1 - tren_{c,h,d}). PQ\_S_{c,d} . XHOUS\_S_{c,h,d}] \quad (38)$$

Where $U_{h,d}$ is utility function of household h in country d, $EH_{h,d}$ is the disposable income of the household as the budget constraint of the household d at country d, $stx_{c,d}$ is the sales tax of commodity c in country d, and $tren_{c,h,d}$ is subsidy rate for consumption of renewable energy of household h. At optimum condition, the household chooses the combination of commodities based on a constant budget share. Therefore, the utility function can be derived into a linear expenditure system as follow:

$$\beta_{c,h,d}.EH_{h,d} = (1 + stx_{c,d}).(1 - tren_{c,h,d}).PQ\_S_{c,d}.XHOUS\_S_{c,h,d} \quad (39)$$

Where $\beta_{c,h,d}$ is the budget share parameter. The disposable income of household d in country d ($EH_{h,d}$) is defined as;

$$EH_{h,d} = \left(1 - \sum_{hh}\sum_{r} strhh_{hh,r,h,d}\right).(1 - savh_{h,d}).(1 - ytax_{h,d}).YH_{h,d} \quad (40)$$

Where $strhh_{hh,r,h,d}$ is the share of transfer amongst households, $savh_{h,d}$ is the shared parameter for household savings, and $ytax_{h,d}$ is the shared parameter of income tax for the household. $YH_{h,d}$ is pre-tax income for the household, that can be defined as:

$$\begin{aligned} YH_{h,d} = & \sum_{f}\sum_{r}(YFAC_{f,r}.sfachh_{r,h,d,f}) \\ & + \sum_{r}(strgrh_{h,r,d}.YGR_{r}) + \sum_{r}(strcohh_{h,r,d}.YCO_{r}) \\ & + \sum_{hh}\sum_{r}(strhh_{h,d,hh,r}.(1 - savh_{hh,r}).(1 - ytax_{hh,r}).YH_{hh,r}) \end{aligned} \quad (41)$$

The first line of Equation (41) is the income from the production factor where $YFAC_{f,r}$ is the total factor income and $sfachh_{r,h,d,f}$ is the shared parameter of factor income of the household. The second line is income from government and corporate, where $strgrh_{h,r,d}$ is the shared parameter of transfer from government to the household, YGR_{r} is the government income, $strcohh_{h,r,d}$ is the shared parameter of transfer from corporate to the household, YCO_{r} is the total corporate income. The third line is transfer from other households.

Government expenditures

Like the household, the government also chooses the combination of commodities based on a constant budget share, subject to the government budget constraint. Notes that the government budget share ($\beta_{c,d}$) is different to the household budget share ($\beta_{c,h,d}$).

$$\beta_{c,d}.EGR_d = PQ\_S_{c,d}.XGOR\_S_{c,d} \tag{42}$$

Where $\beta_{c,d}$ is the budget share parameter for government consumption.

The total income of the government YGR_d consists of several sources. The first line of Equation (43) is income from indirect tax ($itxr_{i,d}$) minus revenue recycled back to the industry ($ritxr_{i,d}$). The second line is income from production factor ownership where $sfacgr_{r,d,f}$ is the shared parameter of production factor income to the government. The third line is income from income tax ($ytaxh_{h,d}$) from the household. The fourth line is income from import tax ($itxm_{c,r,d}$) within the East Asia region while the last line is income from import tariff revenues ($itxn_{c,d}$) from the rest of the world.

$$\begin{aligned} YGR_d = & \sum_i \left[\left(itxr_{i,d} - tco2_{i,d} \right).\ PDOM_{i,d}.XTOT_{i,d} \right] \\ & + \sum_f \sum_r \left(sfacgr_{r,d,f}.YFAC_{f,r} \right) \\ & + \sum_h \left(ytaxh_{h,d}.YH_{h,d} \right) \\ & + \sum_c \sum_r \left(itxm_{c,r,d}.PDOM_{c,d}.XTRAD_{c,r,d} \right) \\ & + \sum_c \left(itxn_{c,d}.PFIMP_{c,d}.EXR_d.XIMP_{c,d} \right) \end{aligned} \tag{43}$$

The government then spend all its income to government expenditure on goods and services (YGR_d) after deducted by transfer to the household ($strgrh_{h,d,r}$), and government savings (SGR_d). Term TCG_d is revenue from a carbon tax that recycled back to the government that increasing the government expenditure.

$$EGR_d = \left(1 - \sum_h \sum_r strgrh_{h,d,r}\right).YGR_d - SGR_d + TCG_d \tag{44}$$

Investment and Export Demands

Regarding investment demand ($XINV\_S_{c,d}$), the investment demand is a function of a fixed share parameter ($\lambda_{c,d}$) of net investment that determines the value of new capital invested in each sector. This is a simplification as IRSA-EA is a static model. Net investment is defined as the aggregate savings of the households, governments, and corporate (SAV_d) minus net transfer of savings-investment between countries ($\sum_r TRSAVINV_{r,d}$).

$$PQ\_S_{c,d}.XINV\_S_{c,d} = \lambda_{c,d}.\left(SAV_d - \sum_r TRSAVINV_{r,d}\right) \tag{45}$$

Export Demands

Export demand ($XEXP_{c,r}$) is defined as a decreasing function of the nominal exchange rate relative to the world price.

$$XEXP_{c,r} = \alpha_{c,r}.\left(\frac{P_{c,r}}{\pi_r.P^w_{c,r}}\right)^{\varepsilon_{c,r}} \tag{46}$$

Where $\alpha_{c,r}$ is a shift parameter, $P_{c,r}$ and $P^w_{c,r}$ are domestic and world prices of commodity c in country r respectively, while π_r is the nominal exchange rate. $\varepsilon_{c,r}$ is demand elasticity.

Balance of Payments

In IRSA-EA, each country has its own balanced of payment. Therefore, the total payment coming in and out of a country should be equal. Therefore, payment coming into a country (ERO_d) is defined as follow:

$$ERO_d = \sum_r TRSAVINV_{d,r} + SRO_d$$

$$+\sum_{h}\sum_{hh}\sum_{r}\left[\left(strhh_{h,d,hh,r}\,.\left(1-savh_{hh,r}\right).\left(1-ytax_{hh,r}\right).YH_{hh,r}\right)\right]$$

$$+\sum_{c}\left(PDOM_{c,d}.XEXP_{c,d}\right)+\sum_{c}\sum_{r}\left(PDOM_{c,d}.XTRAD_{c,r,d}\right) \quad (47)$$

Where the first line is total payment inflow comes from savings-investment transfer from other East Asia countries ($\sum_r TRSAVINV_{d,r}$) and rest of the world (SRO_d). The second line is the international transfer from households. The third line is payment due to exports to the rest of the world and other East Asia countries.

As mentioned earlier, the total payment to and from a country should be equal. Therefore, the outflow payment (YRO_d) is defined as:

$$YRO_d = \sum_{r} TRSAVINV_{r,d}$$

$$+\sum_{h}\sum_{hh}\sum_{r}\left[\left(strhh_{h,r,hh,d}\,.\left(1-savh_{hh,d}\right).\left(1-ytax_{hh,d}\right).YH_{hh,d}\right)\right]$$

$$+\sum_{c}\left(PFIMP_{c,d}.EXR_d.XIMP_{c,d}\right)+\sum_{c}\sum_{r}\left(PDOM_{c,d}.XTRAD_{c,r,d}\right) \quad (48)$$

Where the notations are similar to Equation (47). There is no SRO_d in Equation (48) to avoid double counting. Further, import payment is multiplied by the nominal exchange rate EXR_d .

Carbon pricing mechanism

Following Nurdianto (2011), the unique feature of the IRSA-EA model is integrated carbon emission into the model. The IRSA-EA model assumes that only industries and households emit the carbon emission as follow:

$$XCOI_{e,i,d} = cci_{e,i,d}.XINT\_S_{e,i,d} \quad (49)$$

Where $XCOI_{e,i,d}$ is carbon emission from industry i due to consumption of fossil fuel e in country d, $cci_{e,i,d}$ is carbon-content-intensity for the industrial sector that converts consumption from billion USD into kilotonne of CO2 emissions. Similarly, for households, the following equation holds.

$$XCOH_{e,h,d} = \ cch_{e,h,d}.XHOU\_S_{e,h,d} \tag{50}$$

Where $XCOH_{e,h,d}$ is carbon emission from household h due to consumption of fossil fuel e in country d, $cch_{e,h,d}$ is carbon-content-intensity for household h that converts consumption from billion USD into kilotonne of CO2 emissions.

It is also necessary to set up the sales tax rate due to carbon-content products consumption by industries and households. The sales tax rate a proportion of emission in kilotonne CO2 to billion USD as follow:

$$stx_{e,d} = \frac{cotax_d.\left(\sum_i XCOI_{e,i,d} \ + \ \sum_h XCOH_{e,h,d}\right)}{PQ\_S_{e,d}.\left(\sum_i XINT\_S_{e,i,d} \ + \ \sum_h XHOU\_S_{e,h,d}\right)} \tag{51}$$

$stx_{e,d}$ is the sales tax for consumption of fossil fuel, paid by the industries and the households, $cotax_d$ is a uniform carbon tax in USD per tonne of CO2.

Revenue generated from the carbon tax is defined as follow:

$$TCTR_d = \sum_c \left(stx_{c,d}.PQ\_S_{c,d}.\sum_h XHOU\_S_{c,h,d} \right) + \sum_c \left(stx_{c,d}.PQ\_S_{c,d}.\sum_h XINT\_S_{c,i,d} \right) \tag{52}$$

Where $TCTR_d$ is total carbon tax revenue in country d.

The other important feature of IRSAM-EA is the recycling mechanism of carbon tax revenue into the economy. In the IRSAM-EA model, there are three recycling mechanisms as follow:

$$\mathrm{TCG_d} = \ \mathrm{\alpha g_d.TCTR_d} \tag{53}$$

$$TCI_d = \alpha i_d . TCTR_d \tag{54}$$

$$TCH_d = \alpha h_d . TCTR_d \tag{55}$$

Where TCG_d, TCI_d, and TCH_d are carbon tax revenue distributed to additional spending by the government, indirect tax reduction to the renewable energy industries, and cash transfer to the households to consume more renewable energies. To hold Equation (52) true, the total recycling share αg_d, αi_d, and αh_d should always be equal to one as follow:

$$\alpha g_d + \alpha i_d + \alpha h_d = 1 \tag{56}$$

$$0 \leq \alpha g_d, \alpha i_d, \alpha h_d \leq 1 \tag{57}$$

The distribution of TCI_d is proportional to the investment of renewable energy in the industry i as follow:

$$ritxr_{ren,d} = \frac{shxfac_{ren,d} . TCI_d}{PDOM_{ren,d} . XTOT_{ren,d}} \tag{58}$$

Equation (58) compute the indirect tax rate reduction ($ritxtr_{ren,d}$) for renewable energy industries and $shxfac_{ren,d}$ is the proportion of investment in renewable energies. Similarly, for the households, the carbon tax revenue is recycled proportionally based on the share of renewable energy consumption by the households ($shxhous_{ren,h,d}$).

$$tren_{ren,h,d} = \frac{shxhous_{ren,h,d} . TCH_d}{PQ\_S_{ren,d} . XHOUS\_s_{ren,h,d}} \tag{59}$$

where $tren_{ren,h,d}$ is subsidy rate for the households to consume only on renewable energy.

Closures

To ensure that the number of equations equal to the number of variables, there are several closures in the IRSA-EA model as follow:

1. The output price index is set as a *numeraire*.
2. World export and import prices are exogenous;

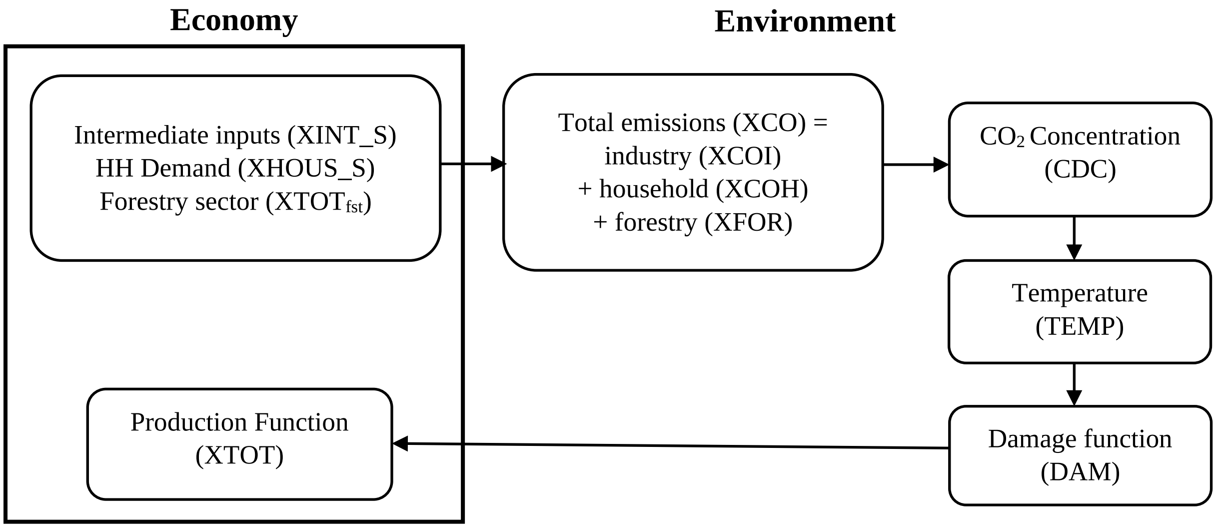
3. All household and corporate savings rates are exogenous;
4. Government savings are exogenous;
5. Indirect tax and import tariff rates are exogenous;
6. All factor supplies are exogenous.
7. Land, natural resources, and capital are immobile;
8. Unskilled and skilled labours are mobile;

The closures of non-labour inputs are set immobile such that they cannot move across industries with average rents are set to be fixed. In contrast, labour is set to be mobile to move into other sectors while keeping sectoral specific wage is set to be fixed. Hence, the analysis in this paper is a short term analysis (Löfgren, Robinson, and Harris 2002).

EXTENSION OF IRSA-EA

This section explains an extension of the original IRSA-EA model, namely a closed-loop IRSA-EA model. Figure 2 describes the closed-loop IRSA-EA model. Carbon emissions come from industry through consumption of energy commodities to produce intermediate inputs; households through energy commodities consumption; and forestry through land uses. Total carbon emissions that are released into the atmosphere accumulate and became concentrated carbon in the atmosphere. In the end, higher carbon concentration leads to a relatively higher temperature and affects sectoral productivity. As sectoral productivity changes, it directly affects total sectoral outputs and affects the final demands of industries and households. In the end, changes in final demand affect changes in carbon emissions.

Figure 2. A closed-loop IRSA-EA in a country



Several equations modification and additional equations are needed to construct a closed-loop IRSA-EA, such as total emissions, carbon concentration in the atmosphere, temperature, and abatement-damage function. These equations are defined following works by Ikefuji et al. (2020) and Nordhaus (2013).

Firstly, total emissions (XCO_d) are defined as a total of carbon emissions from industry ($\mathrm{XCOI}_{e,i,d}$) by using fossil fuel type e in an industry i at country d, households ($\mathrm{XCOH}_{e,h,d}$) by using fossil fuel type e in household h at country d, and forestry (XFOR_d) as a fraction of forestry sector output. The emissions from the industry come from the usage of energy commodities in the production of intermediate inputs ($XINT\_S_{e,i,d}$). Similarly, carbon emissions from the household are generated through the consumption of energy commodities ($XHOU\_S_{e,h,d}$). For the forestry sector, the carbon emissions come from land use that is assumed to be a proportion of the total output produced by the forestry sector ($XTOT_{\prime frs \prime,d}$), represented by parameter τ.

$$XCO_d = \sum_e \sum_i \mathrm{XCOI}_{e,i,d} + \sum_e \sum_h \mathrm{XCOH}_{e,h,d} + \mathrm{XFOR}_d \quad (60)$$

$$\mathrm{XCOI}_{e,i,d} = (1 - \mu 1_{i,d}).\, \mathrm{cci}_{e,i,d}.\, XINT\_S_{e,i,d} \quad (61)$$

$$\mathrm{XCOH}_{e,h,d} = (1 - \mu 2_{h,d}).\, \mathrm{cch}_{e,h,d}.\, XHOU\_S_{e,h,d} \quad (62)$$

$$XFOR_d = \tau.\, XTOT_{'frs',d} \quad (63)$$

Terms $\mu 1_{i,d}$ and $\mu 2_{h,d}$ are emission control rates for industry i and household h respectively. Both emission control rates are equal to zero in the baseline and are exogenous. Further, terms $\mathrm{cci}_{e,i,d}$ and $\mathrm{cch}_{e,h,d}$ denote carbon content for industry and carbon content for the household, respectively.

In terms of carbon concentration in the atmosphere, this paper assumes that carbon concentration comes from the initial carbon concentration ($CDC0_d$) and additional carbon from carbon emissions (XCO_d) as shown in Equation (65). Parameter κ converts the unit of carbon emission from tonne carbon dioxide into part per million (ppm) carbon concentration in the atmosphere. This paper calibrates initial carbon concentration ($CDC0_d$) from 2011 carbon concentration in the atmosphere (CDC_d).

$$CDC_d = \phi 1_d.\, CDC0_d + \phi 2_d.\, \left(\frac{XCO_d}{\kappa}\right) \quad (64)$$

Regarding temperature, this paper assumes that the current temperature comes from the initial temperature ($TEMP0_d$) and concentration of carbon in the atmosphere (CDC_d) in logarithm values as presented in Equation (66). The current temperature ($TEMP_d$) is the temperature difference in degree Celsius between 10 years average temperature in 2011 to 10 years average temperature in 1900. $TEMP$ is used to calibrate the initial temperature ($TEMP0_d$).

$$TEMP_d = \eta 0_d + \eta 1_d.\, TEMP0_d + \eta 2_d.\, log(CDC_d) \quad (65)$$

The damage function ($DAM_{i,d}$) is defined in Equation (67) as a function of damage cost. The damage cost corresponds to temperature. Therefore, a higher temperature leads to a lower value of the damage coefficient.

$$DAM_{i,d} = \frac{1}{1 + \xi_d . TEMP_d^2} \quad (66)$$

Finally, the closed-loop IRSA-EA is conducted by incorporating the abatement-damage function into the top nest of the production function, as presented in Equation (67).

$$\mathrm{XTOT}_{\mathrm{i,d}} = DAM_{i,d} \,.\, \alpha_{\mathrm{i,d}}^{\mathrm{tot}} . \Big(\delta_{\mathrm{i,d}}^{\mathrm{tot}} . \mathrm{XINT\_}SC1_{\mathrm{i,d}}{}^{-\rho^{tot}} \quad (67)$$

$$+ \left(1 - \delta_{\mathrm{i,d}}^{\mathrm{tot}}\right) . \mathrm{XPRIMEN}_{\mathrm{i,d}}{}^{-\rho^{tot}}\Big)^{-\frac{1}{\rho^{tot}}}$$

All parameters for the model ($\phi 1$, $\phi 2$, $\eta 0$, $\eta 1$, $\eta 2$, and ξ) are taken from a simplified DICE. The parameter values as follows: $\phi 1_d$= 0.9902; $\phi 2_d$= 0.6001; $\eta 0_d$=-2.8672; $\eta 1_d$= 0.8954; $\eta 2_d$= 0.4622; ξ_d=0.00265 (Ikefuji et al. 2020).

FINAL REMARKS

This paper aims to provide detail technical guidance to construct the IRSA-EA. IRSA-EA is a multi-country and comparative static CGE model covering Australia, China, Japan, India, South Korea, Indonesia, Malaysia, the Philippines, Singapore, Thailand, Vietnam, and the rest of ASEAN.

There are three highlights of IRSA-EA: flexible production structure, specific recycling mechanism for the renewable electricity sector, and closed-loop inter-regional CGE model. The flexible production structure allows this paper to observe the impacts of changes in prices and quantities, particularly for renewable electricity sectors. The specific recycling mechanisms are the main policy instruments to affect the price of energy and electricity commodities. Finally, the closed-loop inter-regional CGE, namely the closed-loop IRSA-EA, allows this paper to establish a feedback linkage between climate change and the economy for each East Asia country.

IRSA-EA and closed-loop IRSA-EA models are sufficient tools for policy analysis. These models can provide economy-wide impacts of various policy instruments from the trade, environment, and taxes. The nature of static and short to medium term analysis is appropriate for East Asian countries because the policymakers are more interested in the short to medium-term gains than long term gains. The long-term analysis can be done if the model is extended into a dynamic recursive model. However, the long-term analysis is beyond the scope of this paper.

REFERENCES

Adams, Philip D., Peter B. Dixon, Daina McDonald, G. A. Meagher, and Brian R. Parmenter. 1994. "Forecasts for the Australian Economy Using the MONASH Model." *International Journal of Forecasting* 10 (4): 557–71. https://doi.org/10.1016/0169-2070(94)90024-8.

Adelman, Irma, and Sherman Robinson. 1978. *Income Distribution Policy in Developing Countries. A Case Study of Korea*. *Oxford University*. Oxford: Oxford University Press. https://doi.org/10.2307/3439467.

———. 1988. "Macroeconomic Adjustment and Income Distribution. Alternative Models Applied to Two Economies." *Journal of Development Economics* 29 (1): 23–44. https://doi.org/10.1016/0304-3878(88)90069-7.

Adelman, Irma, and Erinc Yeldan. 2000. "The Minimal Conditions for a Financial Crisis: A Multiregional Intertemporal CGE Model of the Asian Crisis." *World Development* 28 (6): 1087–1100. https://doi.org/10.1016/S0305-750X(00)00014-0.

Aguiar, Angel, Maksym Chepeliev, Erwin Corong, Robert McDougall, and Dominique Van Der Mensbrugghe. 2019. "The GTAP Data Base: Version 10." *Journal of Global Economic Analysis* 4 (1): 1–27. https://doi.org/10.21642/JGEA.040101AF.

Azis, Iwan J. 2000. "Simulating Economy-Wide Models to Capture the Transition from Financial Crisis to Social Crisis." *The Annals of Regional Science* 34: 251–78.

Ballard, Charles L., Don Fullerton, John B. Shoven, and John Whalley. 1985. *A General Equilibrium Model for Tax Policy Evaluation*. *A General Equilibrium Model for Tax Policy Evaluation*. Chicago: The University of Chicago Press. https://doi.org/10.7208/chicago/9780226036335.001.0001.

Becker, Charles M., Edwin S. Mills, and Jeffrey G. Williamson. 1986. "Modeling Indian

Migration and City Growth, 1960-2000." *Economic Development and Cultural Change* 35 (1): 1–33.

Ciarli, Tommaso, and Maria Savona. 2019. "Modelling the Evolution of Economic Structure and Climate Change: A Review." *Ecological Economics* 158 (September 2017): 51–64. https://doi.org/10.1016/j.ecolecon.2018.12.008.

Corong, Erwin, Thomas W. Hertel, Robert A. McDougall, Marinos E. Tsigas, and Dominique van der Mensbrugghe. 2017. "The Standard GTAP Model: Version 7." *Journal of Global Economic Analysis* 2 (1): 1–118. https://doi.org/10.21642/jgea.0201xxad.

Coxhead, Ian A., and Peter G. Warr. 1991. "Technical Change, Land Quality, and Income Distribution: A General Equilibrium Analysis." *American Journal of Agricultural Economics* 73 (2): 345–60. https://doi.org/10.2307/1242719.

Dervis, Kemal, Jaime De Melo, and Sherman Robinson. 1982. *General Equilibrium Models for Development Policy*. *World Bank*. Washington, DC : World Bank Group: World Bank Publications.

Dixon, Peter B., B.R. Parmenter, and Alan A. Powell. 1983. "Trade Liberalization and Labor Market Disruption." *Journal of Policy Modeling* 6 (4): 431–54.

Drud, Arne, and Wafik M. Grais. 1983. "Macroeconomic Adjustment in Thailand: Demand Management and Supply Conditions." *Journal of Policy Modeling* 5 (2): 207–31. https://doi.org/10.1016/0161-8938(83)90012-1.

Dufournaud, Christian M., Michael Jerrett, John T. Quinn, and Virginia Maclaren. 2000. "Economy-Wide Effects of Forest Policies: A General Equilibrium Assessment from Vietnam." *Land Economics* 76 (1): 15–27. https://doi.org/10.2307/3147254.

Duraman, I. H., and J. Asafu-Adjaye. 1999. "An Economy-Wide Model of Brunei: Theory, Data and Application.” *Tinjauan - Policy and Management Review* 3 (January): 1–17.

Hamilton, Clive. 1986. “A General Equilibrium Model of Structural Change and Economic Growth, with Application to South Korea.” *Journal of Development Economics* 23 (1): 67–88. https://doi.org/10.1016/0304-3878(86)90080-5.

Ikefuji, Masako, Roger J.A. Laeven, Jan R. Magnus, and Chris Muris. 2020. “DICE Simplified.” *Environmental Modeling and Assessment*, no. October. https://doi.org/10.1007/s10666-020-09738-2.

Johansen, Leif. 1960. *A Multi-sectoral Study of Economic Growth*. Amsterdam: North-Holland.

Kapur, Basant K. 1983. “A Short-Term Analytical Model of the Singapore Economy.” *Journal of Development Economics* 12: 355–76.

Kim, Euijune, and Kabsung Kim. 2002. “Impacts of Regional Development Strategies on Growth and Equity of Korea: A Multiregional CGE Model.” *Annals of Regional Science* 36 (1): 165–80. https://doi.org/10.1007/s001680100071.

Lewis, Jeffrey D. 1991. *A Computable General Equilibrium (CGE) Model of Indonesia*.

Löfgren, Hans, Sherman Robinson, and Rebecca Lee Harris. 2002. *A Standard Computable General Equilibrium (CGE) Model in GAMS*. *Microcomputers in Policy Research* . https://doi.org/338.1’01’51—dc21.

Longva, Svein, Lorents Lorentsen, and Olsen Oystein. 1985. “The Multi-Sectoral Growth Model MSG-4: Formal Structure and Empirical Characteristics.” In *Production, Multi-Sectoral Growth and Planning, Contributions to Economic Analysis*, edited by Finn R. Forsund, Michael Hoel, and Svein Longva, 187–240. Amsterdam: North-Holland.

Lundborg, Per. 1984. “The Nexus between Income Distribution, Trade Policy, and Monopoly Power: An Assessment of the Tin Market.” *Journal of Policy Modeling* 6 (1): 69–79.

https://doi.org/10.1016/0161-8938(84)90050-4.

Martin, Will. 1993. "Modeling the Post-Reform Chinese Economy." *Journal of Policy Modeling* 6: 545–79.

McDonald, Scott, Karen Thierfelder, and Sherman Robinson. 2007. "Globe: A SAM Based Global CGE Model Using GTAP Data." *Economics Working Paper US*, no. May: 1–108. http://www.usna.edu/EconDept/RePEc/usn/wp/usnawp14.pdf.

Mensbrugghe, Dominique Van Der. 2005. "LINKAGE Technical Reference Document." *Development Prospects Group (DECPG)*.

Minot, Nicholas, and Francesco Goletti. 1998. "Export Liberalisation and Household Welfare : The Case of Rice in Vietnam." *American Journal of Agricultural Economics* 80 (4): 738–49.

Nordhaus, William D, and Paul Sztorc. 2013. *DICE 2013R: Introduction and User's Manual*. *Yale University Press*. http://www.econ.yale.edu/~nordhaus/homepage/homepage/documents/DICE_Manual_100413r1.pdf.

Resosudarmo, Budy P. 2002. "Indonesia's Clean Air Program." *Bulletin of Indonesian Economic Studies* 38 (3): 343–65. https://doi.org/10.1080/00074910215538.

Resosudarmo, Budy P., and Erik Thorbecke. 1996. "The Impact of Environmental Policies on Household Incomes for Different Socio-Economic Classes: The Case of Air Pollutants in Indonesia." *Ecological Economics* 17 (2): 83–94. https://doi.org/10.1016/0921-8009(95)00113-1.

Resosudarmo, Budy P, Abdurohman, Arief A Yusuf, and Djoni Hartono. 2021. "Spatial Impacts of Fiscal Stimulus Policies during the 2009 Global Financial Crisis in Indonesia." *Asia-*

Pacific Journal of Regional Science 5 (0123456789): 305–26. https://doi.org/10.1007/s41685-020-00176-2.

Resosudarmo, Budy P, Luky Eko Wuryanto, Geoffrey J.D. Hewings, and Lindsay Saunders. 1999. "Decentralisation and Income Distribution in the Inter-Regional Indonesian Economy." In *Advances in Spatial Sciences: Understanding and Interpreting Economic Structure*, edited by Geoffrey J.D. Hewings, Michael Sonis, Moss Madden, and Yoshio Kimura, 278–315. Heidelberg: Springer-Verlag.

Shishido, Hisanobu. 1982. "Economic Growth and Urbanization: A Study of Japan." *International Regional Science Review* 7 (2): 175–91.

Shoven, J B, and J Whalley. 1972. "A General Equilibrium Calculation of the Effects of Differential Taxation of Income from Capital in the US." *Journal of Public Economics* 1: 281–321.

Siriwardana, Mahinda, and Anoma Iddamalgoda. 2003. "Effects of the Asian Economic Crisis on Singapore and Its Policy Responses : A General Equilibrium Analysis." *UNEAC Asia Papers* 6 (January 2003).

Tan, Kong Yam, Innwon Park, and Mun Heng Toh. 1999. "Strategic Interests of ASEAN-5 in Regional Trading Arrangements in the Asia-Pacific." *Asia Pacific Journal of Management* 16 (3): 449–67. https://doi.org/10.1023/A:1015420416870.

Thorbecke, Erik. 1991. "Adjustment, Growth and Income Distribution in Indonesia." *World Development* 19 (11): 1595–1614. https://doi.org/10.1016/0305-750X(91)90008-6.

Tokunaga, Suminori, Budy P. Resosudarmo, Luky Eko Wuryanto, and Nguyen Tien Dung. 2003. "An Inter-Regional CGE Model to Assess the Impacts of Tariff Reduction and Fiscal Decentralisation on Regional Economy: The Case of Indonesia." *Studies in Regional*

Science 33 (2): 1–25. https://doi.org/10.2457/srs.33.2_1.

Warr, Peter, Jayant Menon, and Arief Anshory Yusuf. 2010. “Regional Economic Impacts of Large Projects: A General Equilibrium Application to Cross-Border Infrastructure.” *Asian Development Review* 27 (1): 104–34.

Whalley, John. 1985. *Trade Liberalization among Major World Trading Areas*. MIT Press.

Yang, Jun, Jikun Huang, Huanguang Qiu, Scott Rozelle, and Mercy A. Sombilla. 2009. “Biofuels and the Greater Mekong Subregion: Assessing the Impact on Prices, Production and Trade.” *Applied Energy* 86 (SUPPL. 1): S37–46. https://doi.org/10.1016/j.apenergy.2009.04.031.

Yusuf, Arief A., and Budy P. Resosudarmo. 2015. “On the Distributional Impact of a Carbon Tax in Developing Countries: The Case of Indonesia.” *Environmental Economics and Policy Studies* 17 (1): 131–56. https://doi.org/10.1007/s10018-014-0093-y.