Working Paper
in Economics and
Development Studies

Department of Economics
Padjadjaran University

No. 201411

The Inter-Regional System of Analysis for ASEAN: A Manual

Ditya A. Nurdianto
(Ministry of Foreign Affairs Republic of Indonesia)

Budy P. Resosudarmo
(Australian National University)

August, 2014

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

For more titles on this series, visit:
http://econpapers.repec.org/paper/unpwpaper/

The Inter-Regional System of Analysis for ASEAN: A Manual

Ditya A. Nurdianto
Ministry of Foreign Affairs
Republic of Indonesia
Jakarta, Indonesia

Budy P. Resosudarmo
Indonesia Project
Arndt-Corden Department of Economics
Crawford School of Public Policy
Australian National University
Canberra, Australia

Contact Person:
Budy P. Resosudarmo
Arndt-Corden Department of Economics
Crawford School of Public Policy
Australian National University
Canberra, ACT 0200
Australia

Email: budy.resosudarmo@anu.edu.au

The Inter-Regional System of Analysis for ASEAN: A Manual

Ditya A. Nurdianto and Budy P. Resosudarmo

Abstract

The Inter-Regional System of Analysis for ASEAN (IRSA-ASEAN) is a static, multi-country, computable general equilibrium (CGE) model. It is a unique model constructed to understand the impact of coordinated and non-coordinated policies, e.g. energy subsidy reduction and carbon tax implementation, on the economic and environmental performances of six of the ten member countriesof ASEAN, namely Indonesia, Malaysia, Philippines, Singapore, Thailand, and Vietnam. Although it is robust enough to be an insightful tool for policy analysis in other issues, e.g. trade, the IRSA-ASEAN model contains a unique feature that makes it particularly valuable for policies related to environment and energy sectors, namely endogenized revenue recycling mechanisms. This paper is intended to become a technical manual for the IRSA-ASEAN model that will help to better analyze empirical results in the authors' other papers.

1. Introduction

This is technical paperthat focuses on the construction of the Inter-Regional System of Analysis for ASEAN (IRSA-ASEAN) computable general equilibrium (CGE) model. The IRSA-ASEAN model is a unique model in its own right with the sole purpose of modeling the Southeast Asian region – using selected ASEAN member countries. This paperprimarily deals with the technical aspect of the model – the empirical results will be discussed in otherpapers. The purpose of this paper is to explain the model so that it can be understood and replicated by others as well as modified to fulfill future analytical needs. This paperalso presents a summary of the IRSA-ASEAN model and how it will be used for empirical analysis in the authors' other papers[1] once combined with the IRSA-ASEAN database.

Along with econometric models, computable general equilibrium (CGE) or appliedgeneral equilibrium (AGE) models have become a standard tool for policy analysis in many countries. Johansen (1960) was a pioneer in the field of multi-sectoral equilibriummodels. However, it was not until the early seventies, perhaps stimulated by Scarf's (1967) work on the computation of equilibria, that several research groups(e.g. three at theWorld Bank) began to build general equilibrium models (Breuss, 1991).

As summarized by Shoven and Whalley (1992), the Walrasian general equilibrium model provides an ideal frameworkfor appraising the effects of policy changes on resource allocation and

[1]ASEAN Economic Community and Climate Change (forthcoming); ASEAN Economic Community and Energy Policy Reform (forthcoming).

for assessingwho gains and loses,both policy impacts are not well coveredby empirical macro models. The term ‘general equilibrium’ corresponds to the well-knownArrow-Debreu model developed in 1954.The main characteristics of the model are as follows. The number of consumers in the model is specified. Each consumer has aninitial endowment of *N* commodities and a set of preferences, resultingin demand functions for each commodity. Market demands are the sum of each consumer's demands. Commodity market demands dependon all prices, continuous, non-negative, homogeneous of degree zero(i.e. no money illusion), and satisfy Walras' law in which at any setof prices, the total value of consumer expenditure equals consumer income.

On the production side, technology is described by either constantreturns-to-scale activities or non-increasingreturns-to-scale productionfunctions. Producers maximize profits. The zero homogeneity of demandfunctions and the linear homogeneity of profits in prices(i.e. doublingall prices doubles profits), imply that only relative prices are of anysignificance in such a model. The absolute price level has no impact onthe equilibrium outcome.Equilibrium in this model is characterized by a set of prices and levelsof production in each industry such that the market demand equals supplyfor all commodities. Since producers are assumed to maximize profits, this implies thatin the constant-returns-to-scalecase,no activity or cost-minimizing techniquefor production functions does any better than break even at theequilibrium prices (Shoven and Whalley, 1992).

A *computable* general equilibrium (CGE) model uses realistic economic data to observe how an economy reacts to any possible changes in, among others, input market, technology, and government policy. There are various types of CGE models. Single-country models are used to study thestructural consequences of exogenous shocks, questions of incomedistribution, and sectoraleffects of tax reforms.The standard national CGE model is a type of CGE model that is mainly concerned with a single country and analyzes its economic structure at the national level. The data source for this type of CGE model usually comes either from the national input-output (I-O) table or the social accounting matrix (SAM). It typically has no sub-national features, thus, aggregating the entire country into one single economy.

This model is also a disaggregated model in the sense that it allows for multi-product industries and multi-industries products. It incorporates detailed estimates of elasticities of substitution between domestically produced products and similar imported products. This type of model usually contains detailed modeling of margin industries and allows the freedom to reclassify variables between the exogenous and endogenous categories.Much recentresearch is devoted to constructing both inter-temporal and recursive dynamic CGE models. Such overlappinggenerations (OLG) models are used to analyze policy changes on economic growth and the allocation of

resources, e.g. taxpolicy and environmental policy. Several attempts have been made tocapture features of imperfect competition and increasing returns to scale. Other single-country models include financial CGE models, which looks specifically at the financial impact of a policy change (Shoven and Whalley, 1992; Resosudarmo *et al*., 2008).More recently, environmental problems and questions of economicgrowth have gained favor with CGE models.

Many single country CGE models have been developed for Southeast Asia countries alone, particularly for Indonesia, such as a model by Lewis (1991), one of the first CGE model for Indonesia; Indorani by Abimanyu (2000), an Indonesian adaptation of the ORANI-G model developed by the Centre of Policy Studies at Monash University used to analyzed trade policies on the environment; financial CGE model by Azis (2000) that consists of real and financial sectors of the Indonesian economy; environmental CGE model by Resosudarmo (2002), the first published inter-temporal dynamics CGE model based on a SAM table; Wayang by Warr (2005), a modified version of ORANI-G with innovative treatments of the agricultural sector; recursive model by Oktaviani *et al.* (2005), a recursive dynamic ORANI-G model; and a model by Yusuf and Resosudarmo (2007), which has 100 rural household and 100 urban household groups and disaggregates energy sectors, as well as incorporates GHG emissions (Resosudarmo *et al*. 2008).

CGE models of other countries in the region include, among others, models for Brunei by Duraman and Asafu-Adjaye (1999); an adaptation of the ORANI-G model for Cambodia by Oum (2009); Malaysia by Jaafar *et al*. (2008); the Philippines by Cororatonand Corong(2006) and Savard (2010); an adaptation of the Global Trade Project Analysis (GTAP) model for Singapore by Siriwardana and Iddamalgoda (2003); Thailand by Karunaratne (1998); and Vietnam by Chan and Dung (2001) as well as Fujii and Roland-Holst (2005).

Multi-country models, on the other hand,deal with cross-boundary issues including, but not limited to,world trade questions. This type of model is mainly concerned with creating a CGE model that captures the country/region/global economy by incorporating many countries into the model. The number of countries in this type of model ranges from two all the way to a global model. Countries, which consist of multiple sectors, are typically inter-connected through trade. The model can then be used to conduct policy analysis on, among others, the impact of tariffs, tax changes, and capital movements on the global economy or a particular country/region economy (Resosudarmo *et al*., 2008). Starting with Harris (1984) who estimated the welfare effectsof the free trade arrangement between the U. S. and Canada, these types of models are being used to study the sectoral consequencesof the completion of the single market on European Community (EC) countries (Harrison *et al*., 1989; Smith and Venables, 1988), andthe European Free Trade Association (EFTA) countries (Norman,1989; Haaland, 1990) as well as the effects on EC and EFTA countries

combined (Norman,1990). Other early works include Whalley (1985) as well as Deardorff and Stem (1986) who use world trademodels to quantify the effects of a multilateral reduction of tariffs within General Agreements on Tariffs and Trade(GATT) on the welfareof individual countries and the world as a whole (Shoven and Whalley, 1992).

Among more recent works, the most widely used is probably the Global Trade Analysis Project (GTAP) model housed in the Department of Agricultural Economics at Purdue University. This is an I-O-based comparative static model with a multi-region, multi-sector general equilibrium model using perfect competition and constant return to scale assumptions (Hertel, 1997). The World Bank also maintains a global CGE model, the LINKAGE. The LINKAGE model is a recursive dynamic global CGE model capturing population and labor dynamics as well as the role of savings and investment on capital accumulation and productivity in multiple countries (Lee *et al.* 2004; Lee and Mensbrugghe, 2004; Mensbrugghe, 2005).Another prominent model is the Globe model which has been calibrated usingdata derived from the GTAP database. Aside from its SAM-based features, this model is distinctive as it uses a 'dummy' region, known as Globe, thatallows for the recording of inter-regional transactions where either the source or destinationare not identified. Examples of such transactions include trade and transportation margins anddata on remittances. The Globe construct provides a general method for dealing with anytransactions data where full bilateral information is missing (McDonald *et al*., 2007).

2. Overview of the IRSA-ASEAN Model

The IRSA-ASEAN model is a multi-country CGE model and is a descendant of the Inter-Regional System of Analysis for Indonesia Five Regions (IRSA-Indonesia5),developed by Resosudarmo *et al.* (2008)in such a way that it bears similarities with the latter in terms of notational use. However, numerous features of the IRSA-ASEAN model also stem from other developments in CGE modeling over the last 20 years; some of these sources of inspiration are direct and easily identified, including one of the first CGE models for Indonesia by Lewis (1991), theGTAP model (Hertel, 1997), and the Globe model (McDonald *et al.*, 2007), such that the IRSA-ASEAN model is a unique model on its own right, both structure-wise (SAM-based) and purpose-wise (energy and environment issues in ASEAN). The IRSA-ASEAN model is a multi-country model that solves at the country level, meaning that optimizations are done at this level. This approach allows price as well as quantities to vary independently by countries, which means that the variation in price as well as in quantity in each country can be observed using this model. This approach enables the user of the model to observe the impact of a specific shock in one country to other countries, the whole ASEAN economy, and the country itself. Figure 1 provides an illustration of the IRSA-ASEAN model.

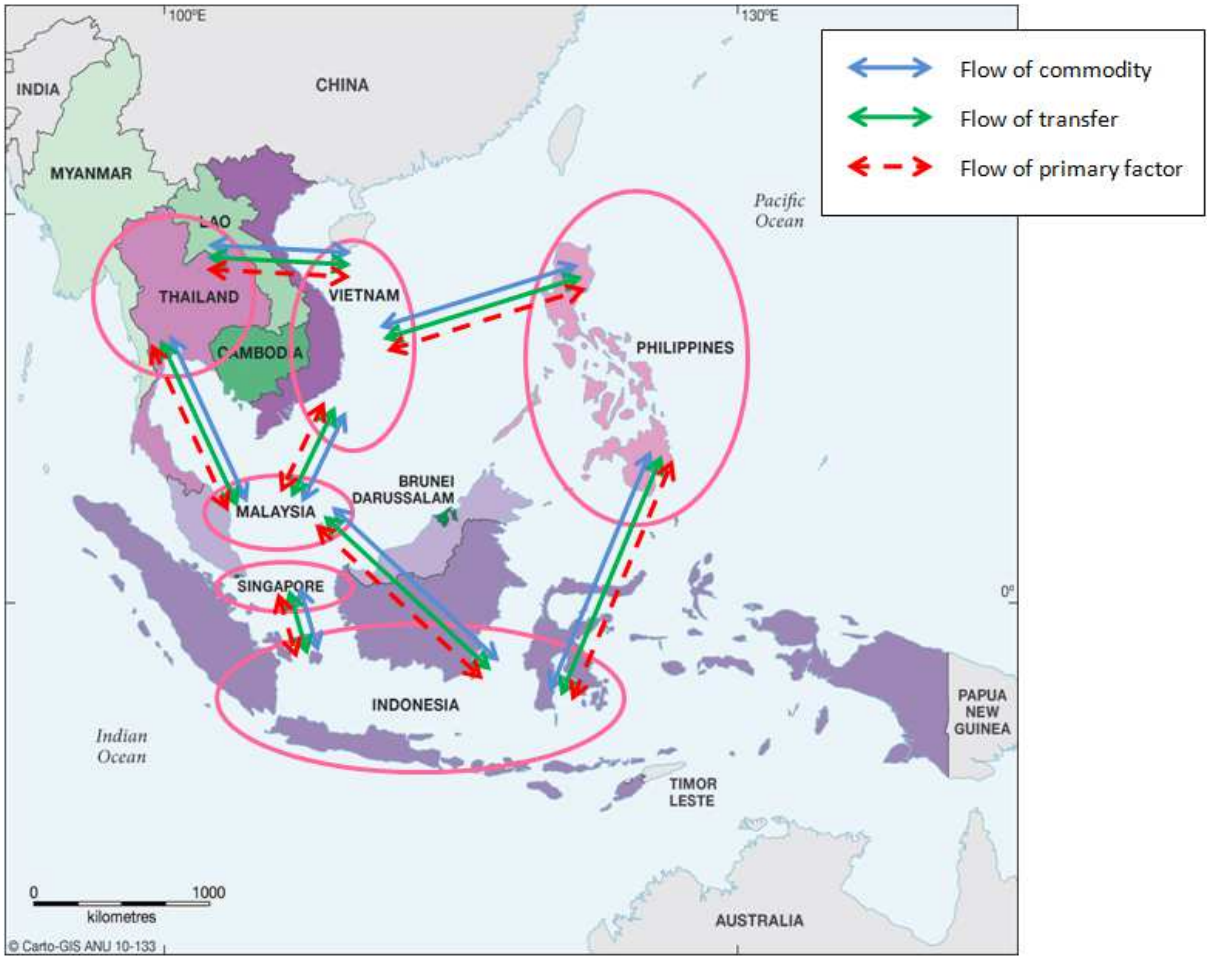

Figure1. The IRSA-ASEAN Model

Figure 1 provides a graphical representation of the IRSA-ASEAN. The IRSA-ASEAN consists of six of ASEAN's member countries, namely Indonesia, Malaysia, Philippines, Singapore, Thailand, and Vietnam. As optimization is done at the country level and, taking into account the 'sovereignty' element of each country, the model uses neither a bottom-up nor a top-down approach.[2] Each country is connected through the flow of commodity – i.e. trade of goods and services, as well as the flow of transfer (i.e. remittance and savings-investment). The model also allows direct transfer of primary factors production,however, due to data scarcity, this last feature is not included in the empirical study.

As a consequence of the sovereignty element in the IRSA-ASEAN model, each country has its own balance of payments as well as savings and investment accounts. Each country deals directly with other countries in terms of trading and is allowed its own set of tariff barriers. For examples, in the IRSA-ASEAN model, each country can export/import goods and services directly to/from the rest

[2] This is in line with real world evidence in which ASEAN, unlike the EU, is not a supranational organization.

of the world (ROW).Figure 2 provides an illustrationof the production structure of the IRSA-ASEAN model.

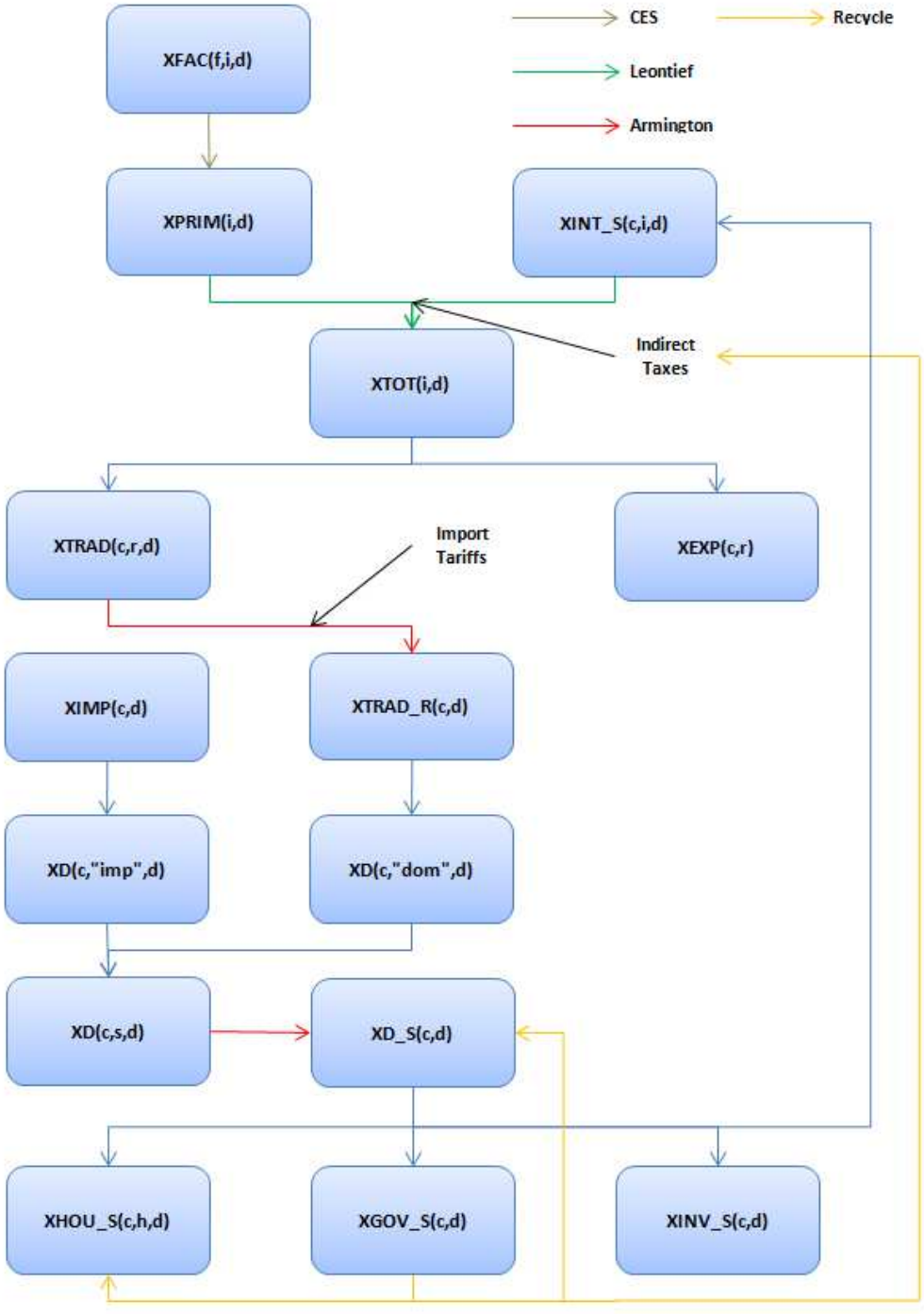

Figure 2. Production Structure of the IRSA-ASEAN Model

The following defines the subscript notations in Figure 2:

- *c* commodity;
- *d* country destination of commodity;
- *f* factor of production;

h household;

i industry;

r countrysource of commodity; and

s source of commodity, composite between *'dom'*[3] and *'imp'*[4].

Meanwhile, *XTOT(i,d)* is output, *XINT_S(c,i,d)* is the intermediate good, and *XPRIM(i,d)* is the primary input. Meanwhile, *XTRAD_R(c,d)* is the domestic demand composite, *XD_S(c,d)* is the domestic and import demand composite, and *XFAC(f,i,d)* is the demand for factor of production.*XEXP(c,r)* represents exports to therest of the world, while the term *XIMP(c,d)* refers to imports from the rest of the world. Meanwhile, XHOU_S(c,h,d) represents household demand, XGOV_S(c,d) represents government demand, and XINV_S(c,d) represents investment demand. Also note that indirect taxes affect production output while import taxes affect the composite demand.*CES* refers to the constant elasticity of substitution (CES) production function, while *Leontief* refers to the fixed proportion production function.

Furthermore, in an open economy CGE model, the standard assumption that is usually applied is the Armington assumption.[5] This assumption implies that imperfect substitutes can have different prices in different countries (Plassmann, 2005). A major benefit of using the Armington assumption is that it permits prices of immobile input factors to differ across regions. If markets are competitive, then differences in input prices lead to differences in output prices. The Armington assumption also provides an intuitive explanation of why consumers do not buy output exclusively from the country with the lowest price.

Another important highlight of the IRSA-ASEAN model deals with the issue of double-dividend. Although the IRSA-ASEAN model can be used for a wide-range of policy simulations, e.g. trade and fiscal simulations, the main motivation for its development in this paper is to assess the economic impact of environment-related policies, namely an energy subsidy reduction and carbon taximplementation. As such, the IRSA-ASEAN model takes a step further with regard to the issue of environment by allowing for the possibility of the double-dividend hypothesis.The model internalizes the double-dividend hypothesis by intrinsically and explicitly incorporating various recycling mechanisms. In this regard, aside from the government increasing its expenditure, the energy subsidy reduction and carbon tax revenuecan either be recycled directly to households, e.g. direct one-time lump-sum cash transfer to low-income households, or recycled back to the industry, e.g. indirect tax reduction, such that it creates a less distortionary tax system, or hypothetically so.

[3] The word '*dom'* refers to domestic, i.e. intra-ASEAN goods and services.

[4] The word *'imp'* refers to import, i.e. extra-ASEAN goods and services.

[5] The term comes from the name Paul Armington, an International Monetary Fund (IMF) economist.

For empirical results, the IRSA-ASEAN model uses the Social Accounting Matrix for ASEAN (ASEAN-SAM) which has been calibrated from the input-output (I-O)-based Global Trade Analysis Project (GTAP) Version 7 Data Base with parameter values, e.g. value-added and Armington elasticities, also obtained from this source. The database uses a common reference year of 2004 and a common currency of United States million dollars (USD million) for all six selected countries in the region. The database has been heavily modified using various country-specific datasets, e.g. social accounting matrices and household income/expenditure surveys, so as to provide greater insight and flexibility for policy analysis.Also, the latest version of the Generalized Algebraic Modeling System (GAMS) program is used to run the IRSA-ASEAN model.

The following lists the additional datasets required to build the so-called ASEAN-SAM. For Indonesia, the additional data needed are (1) 2005 Social Accounting Matrix and (2) 2005 Inter-Regional Social Accounting Matrix (Resosudarmo *et al.*, 2008); Malaysia, (1) 2004/2005 Household Expenditure Survey, (2) 2004 Distribution and Use of Income Accounts and Capital Account, (3) 2000 Population and Housing Census, and (4) 1970 Social Accounting Matrix (Pyatt *et al.*, 1984); Philippines, (1) 2006 Family Income Expenditure Survey, (2) 2000 Social Accounting Matrix (Cororaton and Corong, 2009), and (3) 1997 Family Income Expenditure Survey; Singapore, (1) 2008 Yearbook of Statistics and (2) 2002/2003 Report on the Household Expenditure Survey; Thailand, (1) 2008 Key Statistics, (2) 2002 Household Socio-Economic Survey, and (3) 1998 Social Accounting Matrix (Li, 2002); Vietnam, (1) 2004 Living Standard Survey and (2) 1997 Social Accounting Matrix (Nielsen, 2002). Other data sets needed are the 2010 World Development Indicators, 2008 ASEAN Statistical Yearbook, 2005 ASEAN Statistical Yearbook, 2005 Bilateral Remittance Estimates (Ratha and Shaw, 2007), and 2004 Combustion-Based CO_2 Emissions Data for GTAP Version 7 (Lee, 2008).

The procedures to be followed when constructing the ASEAN-SAM for modeling purposes are divided into three phases. The first phase involves the preparation of the GTAP Version 7 Data Base and transforming it into individual Global SAMs; i.e. Indonesia, Malaysia, Philippines, Singapore, Thailand and Vietnam. Phase 2 is a set of steps required to transform each individual Global SAM into a standard SAM form. Phase 3 is when all individual SAMs are combined to form the ASEAN-SAM. Some adjustments are needed to combine these individual SAMs.Table 1 provides a detailed list of sets of the ASEAN-SAM.

Table 1. List of Sets

Production Sectors[6]		Regions
Agriculture	Trade	Indonesia
Farming	Transportation	Malaysia
Forestry	Communication	Philippines
Fishing	Financial services	Singapore
Coal	Public administration, defense,	Thailand
Oil	health, and education	Vietnam
Gas	Dwellings and other services	Rest of the World
Minerals *nec*		
Food and beverages	**Factors**	**Institutions**
Textile and leather products		
Wood and paper products	Unskilled Labor	Rural-Low Household
Petroleum and coal products	Skilled Labor	Rural-High Household
Chemical, rubber, and	Land	Urban-Low Household
plastic products	Natural resources	Urban-High Household
Mineral products *nec*	Capital	Corporate
Metal products		Government
Manufacturing	**Other Accounts**	
Electricity		
Gas manufacture distribution	Indirect Tax	
Water	Import Tax	
Construction	Savings-Investment	

3. Construction of the IRSA-ASEAN Model[7]

Referring back to Figure 2, the principal activity of any industry is to turn inputs into outputs. In this model, the relationship between inputs and outputs is formalized by a nested CES-Leontief production function in each production sector. The structure of the production function is the same for all sectors. Unlike the basic model of CGE, this model assumes that inputs of production are divided into two categories: the composite of primary factors, i.e. unskilled labor, skilled labor, land, natural resources, and capital; and the intermediate goods. The source of the composite primary factors only comes from the domestic[8] market, but the source of intermediate goods can come from both domestically produced intermediate goods and imported[9] intermediate goods. The nested CES-Leontief production function plays an important role in dealing with the complication of inputs.

[6] Due to technical limitations, Production Sectors have been aggregated from 57 into 26 sectors.
[7] See Appendix 1 for the full list of model equations in GAMS syntax.
[8] Again, the word 'domestic' refers to within ASEAN region. And thus, used interchangeably.
[9] Analogously, the word 'import' refers to extra ASEAN region, i.e. rest of the world.

Within this setup, industries have a separable optimization problem between minimization cost for composite primary factors and minimization cost for intermediate goods.

At the first stage, industries face two different optimization problems: choosing the combination of their primary factors i.e. unskilled labor, skilled labor, land, natural resources, and capital; and their choice of the composite intermediate goods to optimize cost efficiency. At the second stage, each industry minimizes its production cost by choosing the most efficient level of composite primary factors, sometimes called value added, and composite intermediate goods using Leontief production function.[10]

3.1. Demand for Primary Factors

At the first stage, with only five factors of production, a constant elasticity of substitution (CES) function can be used to determine the demand for primary factors. The primary factors' optimization problem for each industry is represented as follows:

$$\min_{\{XFAC_{f,i,d}\}} f\left(XFAC_{f,i,d}\right) \text{ s.t. } XPRIM_{i,d} = CES\left[XFAC_{f,i,d} \mid \sigma_i\right] \qquad [1]$$

with

$$f\left(XFAC_{f,i,d}\right) = \sum_f (PFAC_{f,d} \cdot XFAC_{f,i,d}) \qquad [2]$$

$PFAC_{f,d}$ is a factor price[11], $XFAC_{f,i,d}$ is the demand for primary factor, $XPRIM_{i,d}$ is the composite of primary factors, and $CES\left[XFAC_{f,i,d} \mid \sigma_i\right]$ is a CES functional form that represents the relationship between primary factors. σ_i is the elasticity of substitution for each industry.

Following the derivation by Resosudarmo *et al*. (2008), the solution to Equation 1 is as follows:

$$XFAC_{f,i,d} = \alpha_{i,d}^{\frac{-\rho}{\rho+1}} \cdot XPRIM_{i,d} \cdot \delta_{f,i,d}^{\frac{1}{\rho+1}} \cdot \left(\frac{PFAC_{f,d}}{PPRIM_{i,d}}\right)^{\frac{-1}{\rho+1}} \qquad [3]$$

where $PPRIM_{i,d}$ is the price of composite primary factors paid by industry i in country d [12], $\alpha_{i,d}$ is the shift parameter of value-added, $\delta_{f,i,d}$ is the share parameter of value-added, and $\rho_{i,d}$ is a

[10] Although significantly different in the overall model structure, mathematical and technical notations of the IRSA-ASEAN model are similar to the IRSA-Indonesia5 model developed by Resosudarmo *et al*. (2008).

[11] We are in the perfectly competitive world, where everybody in the economy is a price taker. Therefore, there is no subscript *i* for price because all industries face the same primary factor prices.

parameter of valued-added derived from the elasticity of substitution. The removal of subscripts for $\rho_{i,d}$ in Equation 3 is done for the sake of simplicity.

Meanwhile, market clearing for factors is as follows.

$$(\sum_{i} XFAC_{f,i,d}) + XFACRO_{f,d} = (\sum_{h}\sum_{r} XFACS_{r,h,d,f}) + (\sum_{r} XFGR_{r,d,f}) + (\sum_{r} XFCO_{r,d,f}) + XFRO_{d,f} \quad [4]$$

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, and $XFRO_{d,f}$ is the supply of factors by the rest of the world. The left-hand side variables in the above equation are treated as exogenous.

3.2. Output of Production

At the second stage,a firm's objective is to maximize profit through a Leontief production function. The Leontief production function determines the relationship between all the inputs (a composite of primary factors and intermediate goods)to outputs represented as follows:[13]

$$XTOT_{i,d} = \min\left(XPRIM_{i,d}, XINT\_S_{c,i,d}\right) \quad [5]$$

where $XTOT_{i,d}$ is output for industry *i* at destination country*d*, $XPRIM_{i,d}$ is the primary factors composite, and $XINT\_S_{c,i,d}$ is the intermediate good. The use of the primary factors composite and intermediate goods is assumed to be proportional to the output level of the produced commodity.

$$XPRIM_{i,d} = \alpha_{i,d}^{prim} \cdot XTOT_{i,d} \quad [6]$$

$$XINT\_S_{c,i,d} = \alpha_{c,i,d}^{\text{int}} \cdot XTOT_{i,d} \quad [7]$$

where $\alpha_{c,i,d}^{\text{int}}$ is the proportion of intermediate goods used to produce the output and $\alpha_{i,d}^{prim}$ is the proportion of composite primary factors used to produce the output.

---

[12] The price of composite primary factors for each industry is different since each industry has a different combination of primary factors.

[13] This production function was introduced by a Russian-American economist, Wassily Leontief. He was a pioneer in the development of input-output analysis. In an input-output analysis, production is assumed to take place with fixed-proportions technology.

Admittedly, one important outcome, and perhaps limitation, to this setup is that*endogenous* substitution between intermediate inputs is not allowed. This is mainly due toa technical limitation in which convergence, i.e. solution, to a model that allows endogenous substitution between intermediate goods is difficult to achieve once a 'shock' is introduced. In other words, GAMS cannot solve the model as there are too many equations due to the number of commodities multiplied by the number of countries in the IRSA-ASEAN model.

However, the model allows *exogenous* substitution. To put it briefly, a constant can be introduced into Equation 7 (e.g. 0.9 for the coal sector) which basically means that a less amount of coal (approximately 10 percent)is needed to achieve the same amount of output. By extension, the share uses of other inputs have increased, i.e. substitution effect, as well as share uses of primary factors, i.e. efficiency effect. As such, in this way, substitution and efficiency effects can be observed in the model despite the use a Leontief production function.

3.3. Zero Profit Conditions and Market Clearing for Commodities

At optimum, the total amount of commodity *c* supplied is produced by satisfying the first order necessary condition (FONC) of its optimization problem, where the marginal revenue of producing the commodity equals its marginal cost. This condition can also be represented by the optimum of its dual problem that holds under a zero profit condition. Zero profit condition is the situation where total revenue from producing the commodity equals its total cost. The total revenue is represented by the arguments on the left-hand side of Equation 8 and the total cost is shown on the right-hand side.

$$(1-itxr_{i,d}+tco2_d)\cdot PDOM_{i,d}\cdot XTOT_{i,d}=PPRIM_{i,d}\cdot XPRIM_{i,d} + \sum_c\left[(1+stx_{c,d})\cdot PQ\_S_{c,d}\cdot XINT\_S_{c,i,d}\right] \qquad [8]$$

where $itxr_{i,d}$ is the indirect tax rate, $tco2_d$ is the indirect tax reduction rate recycled from the energy subsidy reduction or carbon tax revenue, and $stx_{c,d}$ is the sales tax rate when a carbon tax is implemented. Note that in the absence of an energy subsidy reduction or a carbon taximplementation or, $tco2_d$ and $stx_{c,d}$ are empty sets.

In an equilibrium condition, all the output supplied for commodity *c* from region *r* $\left(XTOT_{c,r}\right)$ must equal the sum of the demand for commodity *c* at all domestic destinations $\left(XTRAD_{c,r,d}\right)$ and the demand for commodity *c* from outside the region $\left(XEXP_{c,r}\right)$, i.e. rest of the world.

$$XTOT_{c,r} = (\sum_{d} XTRAD_{c,r,d}) + XEXP_{c,r} \quad [9]$$

3.4. Inter-Regional Trade and Import

Using the CES aggregation function, we can establish the demand of commodity *c* with source country*r* to destination country*d*.

$$\min_{\{XTRAD_{c,r,d}\}} f\left(XTRAD_{c,r,d}\right) \text{ s.t. } XTRAD\_R_{c,d} = CES\left[XTRAD_{c,r,d} \mid \sigma_{c,d}\right] \quad [10]$$

with

$$f\left(XTRAD_{c,r,d}\right) = \sum_{r}\left[(1+itxm_{c,r,d}) \cdot PDOM_{c,d} \cdot XTRAD_{c,r,d}\right] \quad [11]$$

where $PDOM_{c,r}$ is the producer price for commodity *c* at source country*r*, $XTRAD_{c,r,d}$ is the demand of commodity *c* from source country*r* to destination country*d*, and $CES\left[XTRAD_{c,r,d} \mid \sigma_{c,d}\right]$ is a CES functional form representing the demand for commodity *c* from all source countries to a destination country*d*, with $\sigma_{c,d}$ as the elasticity of substitution for commodity *c* from a different source country*r* at a destination country*d*.

This optimization problem leads to the following solution:

$$XTRAD_{c,r,d} = \alpha_{c,d}^{\frac{-\rho}{1+\rho}} \cdot XTRAD\_R_{c,d} \cdot \delta_{c,r,d}^{\frac{1}{\rho+1}} \cdot \left[\frac{(1+itxm_{c,r,d}) \cdot PDOM_{c,r}}{PQ_{c,"dom",d}}\right]^{\frac{-1}{\rho+1}} \quad [12]$$

where $PQ_{c,"dom",d}$ is the domestic purchaser's price for commodity *c* at country*d* as $itxm_{c,r,d}$ is the import tariff for commodity *c* from country *r* to country *d.*

3.5. Demand for Commodities

Forwithin ASEAN, the demand for commodity *c* is established through a CES aggregation of the commodity from source country *r* to a destination country *d* $\left(XD_{c,"dom",d}\right)$ identical to $XTRAD\_R_{c,d}$, such that, the following identity holds:

$$XTRAD\_R_{c,d} = XD_{c,"dom",d} \quad [13]$$

Meanwhile, demand for commodities from outside of ASEAN holds the following identity:

$$XIMP_{c,d} = XD_{c,"imp",d} \quad [14]$$

where $XIMP_{c,d}$ is the demand for commodity*c* fromoutside of ASEANto destination country *d*.

$XD_{c,"dom",d}$ and $XD_{c,"imp",d}$ are then combined using a CES aggregator.

$$\min_{\{XD_{c,s,d}\}} f\left(XD_{c,s,d}\right) \text{ s.t. } XD\_S_{c,d} = CES\left[XD_{c,s,d} \mid \sigma_{s,d}\right] \quad [15]$$

where

$$f\left(XD_{c,s,d}\right) = \sum_{s}(PQ_{c,s,d} \cdot XD_{c,s,d}) \quad [16]$$

The same explanation applies for Equations 10 and 11. However,attention must be given to the subscript *s* = {*'dom', 'imp'*}the above equations. The subscript represents the source of the commodity, where'*dom'*represents domestic sources, i.e. imports from within ASEAN, and *'imp'*stands for imports from outside of ASEAN.

The solution for the above optimization problem is:

$$XD_{c,s,d} = \alpha_{c,d}^{\frac{-\rho}{1+\rho}} \cdot XD\_S_{c,d} \cdot \delta_{c,r,d}^{\frac{1}{\rho+1}} \cdot \left(\frac{PQ_{c,s,d}}{PQ\_S_{c,d}}\right)^{\frac{-1}{\rho+1}} \quad [17]$$

where $XD\_S_{c,d}$ is the demand for commodity *c* from composite sources, i.e. domestic countries,and imported from outside of ASEAN, at destination country *d*. Meanwhile, $PQ_{c,s,d}$ is the purchaser's price of commodity *c* from source country *s* at destination country *d*, whereas $PQ\_S_{c,d}$ is the purchaser's price of commodity *c* from composite sources at destination country *d*.

Part of the total demand for commodity *c*, $XD\_S_{c,d}$, is then used as an intermediate input $\left(XINT\_S_{c,i,d}\right)$. The remainder will be consumed by households$\left(XHOU_S_{c,h,d}\right)$, governments $\left(XGOR\_S_{c,d}\right)$, and investment purposes$\left(XINV_S_{c,d}\right)$. That is:

$$XD\_S_{c,d} = (\sum_{i} XINT\_S_{c,i,d}) + (\sum_{h} XHOU\_S_{c,h,d}) + XGOR\_S_{c,d} + XINV\_S_{c,d} \quad [18]$$

3.6. Household Optimization

Final users of commodity *c* consist of households, governments, and investments. In this model, all three share a common solution to their respective optimization problem. Each chooses its combination of commodities based on a constant budget share. Similarly, each household maximizes its utility:

$$\max_{\{XHOU\_S_{c,h,d}\}} U_{h,d} = f\left(XHOU\_S_{c,h,d}\right)$$
$$\text{s.t. } EH_{h,d} = \sum_{c}\left[(1+stx_{c,d})\cdot PQ\_S_{c,d}\cdot XHOU\_S_{c,h,d}\right] \quad [19]$$

The utility function gives a linear expenditure system in which the demand for one specific commodity *c*for household *h* at destination *d* is defined as follows:

$$\beta_{c,h,d}\cdot EH_{h,d} = (1+stx_{c,d})\cdot PQ\_S_{c,d}\cdot XHOU\_S_{c,h,d} \quad [20]$$

where $\beta_{c,h,d}$ is the budget share parameter. $EH_{h,d}$ is the household disposable income that comes from the following identity condition:

$$EH_{h,d} = (1-\sum_{hh}\sum_{r} strhh_{hh,r,h,d})\cdot(1-savh_{h,d})\cdot(1-ytaxh_{h,d})\cdot YH_{h,d} \quad [21]$$

where $strhh_{hh,r,h,d}$ is the share parameter for inter-household transfer, e.g. remittance, $savh_{h,d}$ is the share parameter for household savings, and $ytaxh_{h,d}$ is the share parameter for household income tax. Meanwhile, $YH_{h,d}$ is the pre-tax household income that comes from the following identity:

$$\begin{aligned} YH_{h,d} &= \sum_{f}\sum_{r}(YFAC_{f,r}\cdot SFACHH_{r,h,d,f}) \\ &+ \sum_{r}(strgrh_{h,r,d}\cdot YGR_{r}) + \sum_{r}(strcohh_{h,r,d}\cdot YCO_{r}) \\ &+ \sum_{hh}\sum_{r}\left[strhh_{h,d,hh,r}\cdot(1-savh_{hh,r})\cdot(1-ytaxh_{hh,r})\cdot YH_{hh,r}\right] \\ &+ strco2h_{h,d}\cdot TCH_{d} \end{aligned} \quad [22]$$

$YFAC$ is the total factor income, $SFACHH$ is the share factor income of household, YGR is the government revenue, YCO is the corporate revenue, while $strgrh_{h,r,d}$ and $strcohh_{h,r,d}$ arethe share transfer to household respectively. Note that only households receive income from both unskilled and skilled labors. Lastly, TCH is the nominal energy subsidy reduction or carbon tax revenue recycled back to households and $strco2h_{h,d}$ is the share parameter. Two important things

to note here are that the third line in Equation 22 adds up to how much the household *receives* from other households; while in Equation 21, the summation of $strhh_{hh,r,h,d}$ adds up to how much the household *gives* to other households. Lastly, the fourth line in Equation 22 refers to the second recycling mechanism aside from the $tco2_d$ mechanism in the previous section.

3.7. Government Optimization

Similarly, the government also needs to find its optimum combination of commodities from different sources. As such, the government also chooses its combination of commodities based on a constant budgetshare, subject to its budget constraint.

$$\beta_{c,d} \cdot EGR_d = PQ\_S_{c,d} \cdot XGOR\_S_{c,d} \quad [23]$$

where $\beta_{c,d}$ is the budget share parameter for government consumption. Note that the budget share parameter in Equation 23 is different from the share parameter in Equation 20, which refers to the budget share parameter of household consumption. Meanwhile, EGR is government expenditure. As stated, Equation 23 is subject to government income defined by the following identity:

$$\begin{aligned} YGR_d = & \sum_i \left[(itxr_{i,d} - tco2_d) \cdot PDOM_{i,d} \cdot XTOT_{i,d} \right] \\ & + \sum_f \sum_r (SFACGR_{r,d,f} \cdot YFAC_{f,r}) + \sum_h (ytaxh_{h,d} \cdot YH_{h,d}) \\ & + \sum_c \sum_r (itxm_{c,r,d} \cdot PDOM_{c,d} \cdot XTRAD_{c,r,d}) \\ & + \sum_c (itxn_{c,d} \cdot PFIMP_{c,d} \cdot XIMP_{c,d} \cdot EXR_d) \end{aligned} \quad [24]$$

Briefly explained, the first line in Equation 24 refers to government income from indirect taxminus the amount of revenue recycled back to the industry. The second line refers to government income from factors of production that it owns, i.e. land, natural resources, and capital, as well as income tax. The third line refers income generated from import tariffson goods and services from countries within ASEAN, while the fourth line refers to income generated from import tariffs on goods and services from countries outside the region, i.e. rest of the world.

Equations23and 24 are linked by the following identity:

$$EGR_{h,d} = (1 - \sum_h \sum_r strgrh_{h,d,r}) \cdot YGR_d + TCG_d - SGR_d \quad [25]$$

Equation 25 shows that government expenditure on goods and services must first be reduced by the total government subsidy to households and government savings, SGR.It is important to note that government subsidy in Equation 24 is not an empty set regardless of whether or not an energy

subsidy is eliminated and a carbon tax is implemented. Also, government savings can be a negative value, which will then represent a government deficit. Lastly, TCG is the third mechanism by which the government can recycle carbon tax revenue in which the government increases its consumption.Note that in this case, all the revenue held by the government is recycled back to the economy through an increase in its expenditure and none is used to increase/decrease government saving/deficit.

In the case of an energy subsidy reduction, although the equation is identical, the signs are slightly different in Equations 24 and 25. For sectors where a government subsidizes the industry, indirect tax rate represented by $itxr_{i,d}$ has a negative value. As such, when an energy subsidy is eliminated, government income automatically increases. In variants where some of that extra revenue is transferred back to households and industries, TCG must be a negative value to avoid double-accounting. In other words, TCG must be a negative value equal to the amount of revenue recycled back to households and industries.[14]

3.8. Investment and Export Demands

Two additional demands for commodity *c* arise from investment and export. For the former case, investment demand adheres to the following identity:

$$PQ\_S_{c,d} \cdot XINV\_S_{c,d} = \lambda_{c,d} \cdot (SAV_d - \sum_r TRSAVINV_{r,d}) \quad [26]$$

where $\lambda_{c,d}$ is the share parameter and SAV_d is the aggregatesavings in country *d* from household, government, corporate, and transfer savings. A savings transfer, $TRSAVINV$, refers to a net transfer of savings-investment between countries.[15]

This model also allows foreign demand for locally-produced goods to be price-sensitive. If the local price of a good rises relative to the world price, export demand will fall. That is:

$$XEXP_{c,r} = \alpha_{c,r} \left(\frac{P_{c,r}}{\pi_r P^w_{c,r}} \right)^{\varepsilon_{c,r}} \quad [27]$$

where $\alpha_{c,r}$ is a shift parameter, $P_{c,r}$ is domestic price, π_r is nominal exchange rate[16], and $\varepsilon_{c,r}$ is the elasticity of demand. In words, exports of commodity *c* are a declining function of the price in foreign currency, relative to the world price.

[14] This feature will be explained further in a later section that deals with revenue recycling mechanism.
[15] Although a bit uncommon, the nominal exchange rate is needed to reconcile the data derived from the GTAP database and the CGE model.

3.9. Balance of Payments and Model Closures

One final important account before model closures deals with the balance of payment. As this is a multi-country model without the existence of a supranational entity, each country has its own set of balance of payment. In order words, total transfer payment coming into the country must equal total transfer payment going out of the country.

$$\begin{aligned} ERO_d &= \sum_r TRSAVINV_{d,r} + SRO_d \\ &+ \sum_h \sum_{hh} \sum_r \left[strhh_{h,d,hh,r} \cdot (1 - savh_{hh,r}) \cdot (1 - ytaxh_{hh,r}) \cdot YH_{hh,r} \right] \\ &+ \sum_c (PDOM_{c,d} \cdot XEXP_{c,d}) \\ &+ \sum_c \sum_r (PDOM_{c,d} \cdot XTRAD_{c,d,r}) \quad , \quad XTRAD_{c,r,d} \neq XTRAD_{c,d,r} \end{aligned} \tag{28}$$

Equation 28 shows that total payment inflow comes from: the total value of savings-investment transfers (i.e. financial transfers) coming from other ASEAN countries, $\sum_r TRSAVINV_{d,r}$, and rest of the world, SRO; international inter-household transfers (e.g. remittance; total export value to rest of the world); and total export value goods and services to other ASEAN countries.

By definition, payment coming in must equal payment going out. Payment outflow is defined as follows:

$$\begin{aligned} YRO_d &= \sum_r TRSAVINV_{r,d} \\ &+ \sum_h \sum_{hh} \sum_r \left[strhh_{h,r,hh,d} \cdot (1 - savh_{hh,d}) \cdot (1 - ytaxh_{hh,d}) \cdot YH_{hh,d} \right] \\ &+ \sum_c (PFIMP_{c,d} \cdot XIMP_{c,d} \cdot EXR_d) \\ &+ \sum_c \sum_r (PDOM_{c,d} \cdot XTRAD_{c,r,d}) \quad , \quad XTRAD_{c,r,d} \neq XTRAD_{c,d,r} \end{aligned} \tag{29}$$

Equation 28 must equal Equation 29 in order to have a *balanced* balance of payment, such that the two equations are similar in form with important differences in the subscripts. Other things to note include the absence of any transfer of savings-investment to rest of the world. As previously mentioned, transfers of savings-investment between country refer to the *net* transfers such that SRO is not needed as to avoid double accounting. Also, total import value from rest of the world is calculated at local currency unit, and thusthe necessity for the nominal exchange rate.[17]

[16] This leads to a limitation of the model in which nominal exchange rate only exists between each ASEAN country with the rest of the world. Exchange rate movement between ASEAN countries are not taken into consideration in this model due to the complexity it will entail.

[17] Another reason for the nominal exchange rate is *technical* in nature, which is it allows movement in the balance of payments when running the model using GAMS.

Lastly, closure is an assumption to close the mathematical system/model where closing the system means the number of equations equal to the number of unknown variables. If theseconditions are not fulfilled then the model cannot be solved. In order to close IRSA-ASEAN model, the following closures, among others, are introduced to guarantee that the system is solvable:

1. All factor supplies are exogenous;
2. Unskilled and skilled labors are mobile;
3. Land, natural resources, capital are immobile;
4. All household and corporate savings rates are exogenous;
5. All shares of inter-institutional transfer rates are exogenous;
6. World import prices are exogenous;
7. Indirect tax and import tariff rates are exogenous; and
8. Output price index is set as a *numeraire*.

3.10. Carbon Pricing Mechanism[18]

The carbon pricing mechanism is a unique feature of the IRSA-ASEAN model in which CO_2emissions data is held as a separate matrix, and yet, intrinsically and explicitly integrated in the model. Emissions basically come from the household and industrial sectors, albeit some service sectors emit zero emissions as shown through the following equations.

$$XCOH_{e,h,d} = cch_{e,h,d} \cdot XHOU\_S_{e,h,d} \quad [30]$$

and

$$XCOI_{e,i,d} = cci_{e,i,d} \cdot XINT\_S_{e,i,d} \quad [31]$$

$XCOH_{e,h,d}$ is the total CO_2emissions from households consumption of fossil fuels, i.e. coal, petroleum products, and gas, denoted by the subscript *e.* Similarly, $XCOI_{e,i,d}$ is the total CO_2emissionsfrom the industrial use of fossil fuels. Now, $cch_{e,h,d}$ and $cci_{e,i,d}$ are the carbon-content-intensity for each household and industrial sector, which converts consumption in USD million into kiloton of CO_2emissions. It then follows that carbon-content-intensity is the highest for coal,

[18] The carbon pricing mechanism is explained before the energy subsidy reduction because the equations involved are more complex. As such, construction priority for the second case study took precedence before the first case study to ensure the feasibility of the model.

followed by petroleum products and, least of all, gas. This holds true for all country although carbon-content-intensity may differ across households, industries, and countries.

With regard to carbon pricing, the most important equation deals with setting the rates for the carbon tax.

$$stx_{e,d} = cotax_d \cdot (\sum_i XCOI_{e,i,d} + \sum_h XCOH_{e,i,d}) \\ / PQ\_S_{e,d} \cdot (\sum_i XINT\_S_{e,i,d} + \sum_h XHOU\_S_{e,h,d}) \quad [32]$$

$stx_{e,d}$ is the sales tax for the consumption and use of fossil fuels born by households and industries, while $cotax_d$ is the level of carbon tax, e.g. USD 10 per ton of CO_2emissions. Note that the governments neither produce CO_2emissions nor pay for it. Revenue generated from the carbon tax is as follows:

$$TCTR_d = \sum_c (stx_{c,d} \cdot PQ\_S_{c,d} \cdot \sum_h XHOU\_S_{c,h,d}) \\ + \sum_c (stx_{c,d} \cdot PQ\_S_{c,d} \cdot \sum_i XINT\_S_{c,i,d}) \quad [33]$$

The following equations determine how revenue generated from Equation 33 are recycled back into the economythrough three different mechanisms, namely household cash transfer, industrial tax reduction, and government expenditure increase respectively:

$$TCH_d = \alpha h_d \cdot TCTR_d \quad [34]$$

$$TCI_d = \alpha i_d \cdot TCTR_d \quad [35]$$

$$TCG_d = \alpha g_d \cdot TCTR_d \quad [36]$$

$$\alpha h_d + \alpha i_d + \alpha g_d = 1 \quad \text{and} \quad 0 \le \alpha h_d, \alpha i_d, \alpha g_d \le 1 \quad [37]$$

Equation 37is in actuality not so much an equation as it is a *share* condition *exogenously* determined to ensure that the amount of revenue generated equals the amount of revenue recycled back into the economy.

Lastly, for the case of indirect tax reduction, one final equation is added.

$$TCI_d = tco2_d \cdot \sum_i (PDOM_{i,d} \cdot XTOT_{i,d}) \quad [38]$$

In a few words, Equation 35 establishes the indirect tax reduction rate in each country. As $tco2_d$ is a uniform rate across industries within a country, in cases where there is no indirect tax, this then becomes an industrial subsidy. Additionally, the nominal value of the tax reduction is proportional to the industry size. Although this mechanism implies that carbon-intensive industries (e.g. electricity sector) also receive tax reductions, bear in mind that a carbon tax is still in effect,which means that the policy is not ineffective. In fact, this mechanism allows for the possibility of a rebound effect to occur, albeit this may create technical problems in cases where the net effective tax is relatively small and the carbon tax value is relatively high.[19]

3.11. Subsidy Reduction Mechanism

The recycling mechanism in an energy subsidy reduction scenario is in actuality quite similar to the carbon pricing recycling mechanism. However, the main difference lies in the fact that Equation 33 is unused in this scenario. Instead of generating a new revenue from carbon tax, the revenue is *fixed* equal to the amount of revenue generated from the energy subsidy reduction as shown by the following identity:

$$TCTR_d = \sum_c \left[(itxr_{i,d}^{new} - itxr_{i,d}^{old}) \cdot PDOM_{i,d}^{old} \cdot XTOT_{i,d}^{old} \right] \quad [39]$$

Following this change, the conditional rule for Equation 4.33 has to be modified as follows:

$$\alpha h_d + \alpha i_d + \alpha g_d = 0 \quad \text{and} \quad 0 \le \alpha h_d, \alpha i_d \le 1 \quad \text{and} \quad -1 \le \alpha g_d \le 0 \quad [40]$$

Equation 40 may appear somewhat confusing. However, suppose now that the government decides to retain all the revenue generated to increase its consumption, then αh_d = 0, αi_d = 0, and αg_d = 0. This in turn affects Equation 24 in which government income increases as the energy subsidy is eliminated. In turn, all of this revenue is used to increase government expenditure in Equation 25 without any reduction at all, as neither households nor industries are given a share of the revenue generated.

Suppose now that the government decides to transfer half of the subsidy reduction to households in the form of a single lump sum payment, and the other half to increase its own consumption, then αh_d = 0.5, αi_d = 0, and αg_d = -0.5. This in turn affects Equation 34 followed by Equation 22 for the household case, which means that household income increases by the amount of revenue transferred by the government. Bear in mind that forthe government part, because of

[19] This technical difficulty will be discussed further in the following empirical section.

the negative government share sign then TCG is a negative value. However, the overall government consumption may still increase in Equation 25because the decrease is smaller (i.e. half) than the increase in government income, as reflected by Equation 24, due to the subsidy reduction.

4. Financial Flowof the IRSA-ASEAN Model

Following the equations described in the previous section, Figure 3 illustrates the financial flow of the IRSA-ASEAN model.Admittedly, this is a simplified schematic as it provides details of the flow within one country, with only one other country representing all the others, including rest of the world. Nevertheless, Figure 3 provides a useful tool to see how changes occur throughout the economy, i.e. impact path analysis. In other words, it summarizes the IRSA-ASEAN model.

Some highlights from Figure 3 include the three different mechanisms by which carbon tax revenue can be recycled back into the economy. The first mechanism is when the government uses all revenue generated to proportionally increase its expenditures. The second mechanism is when government chooses to redistribute some, or all, of the revenue generated to low-income households in both rural and urban areas in the form of a one-time lump-sum direct cash transfer to each household group. Note that high-income households in both rural and urban areas do not receive such a transfer. The third mechanism is more complicated in terms of practical and technical implementation. This mechanism occurs when the government recycles the revenue back to the industrial sector in the form of an indirect tax reduction proportional to the sectoral output size. Understandably, the larger the industry, the greater the nominal reduction will be. There are, of course, a number of possible combinations of these three mechanisms and this will explained further in the policy simulations in otherpapers.

One final note with regards to the recycling mechanisms is the fact that different combinations of these mechanisms are possible. Indeed, it unlikely that in the real world situation, a government would choose to adopt solely one of these mechanisms. Accordingly, policy simulations conducted in otherpapers take this into account and create a number of combinations.

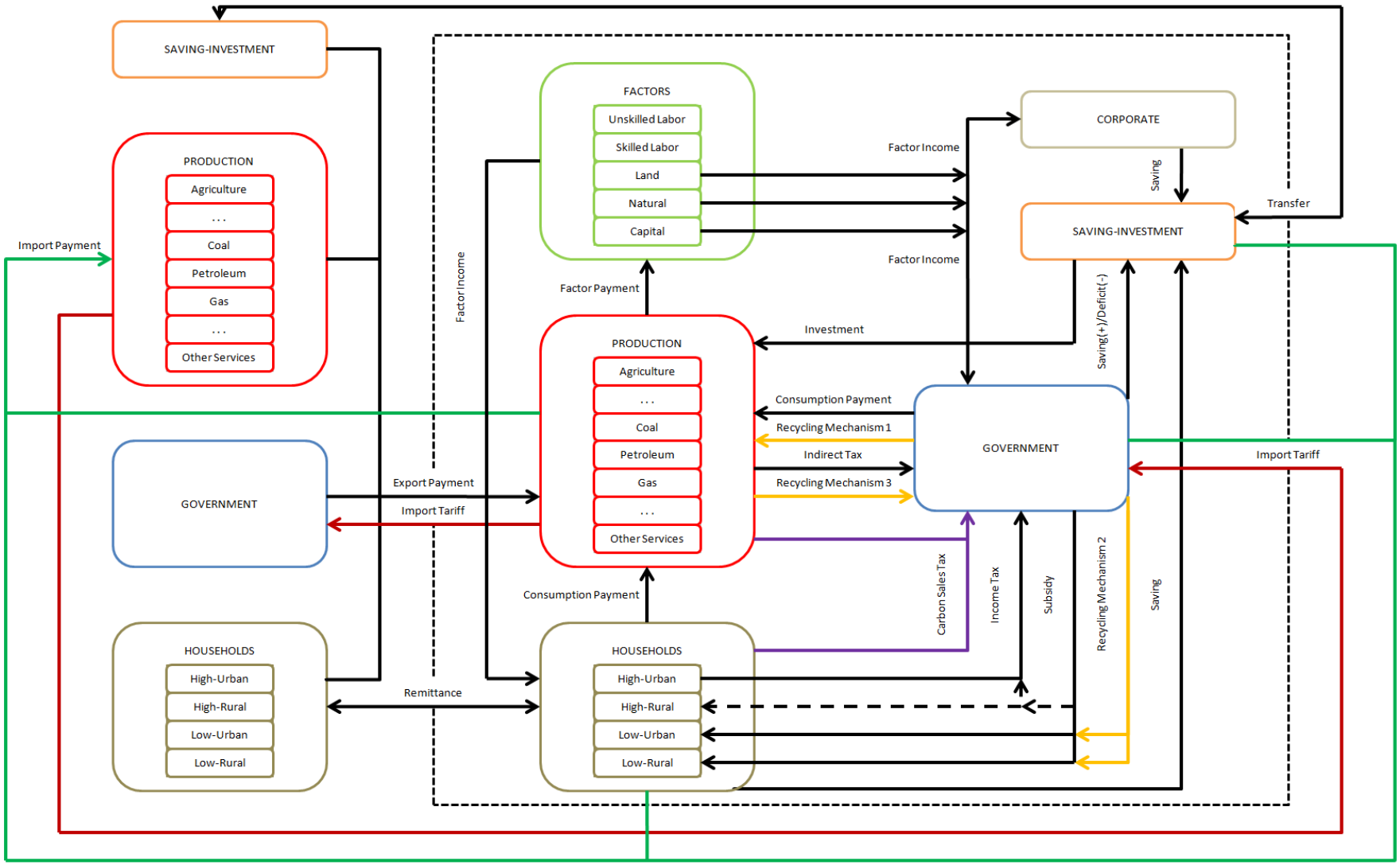

Figure 3. Financial Flow of the IRSA-ASEAN Model

Another important highlight from Figure3 is how it shows the path effect of each mechanism once an energy subsidy is eliminatedor a carbon tax is implemented. For the first recycling mechanism in which the government increases its expenditure of goods and services, this will have a direct effect on production activities. Although production activities might contract due to the elimination of an energy subsidy or the implementation of a carbon tax, the increase in government expenditure also expands production activities due to the increase in demand. Whether the net effect is positive or negative is yet unknown. It is certain, however, that this will have an effect on the demand for primary factor inputwithin the country and intermediate input from both within and outside the country. This will also affect the government of other countries through the increase/reduction of total import tariff value. Within the country itself, aside from the feedback effect to the governmentthrough the indirect tax, a change to primary factor input demand affects factor income payment to households, corporate, and the government. This in turn affects these institutions' consumption of goods and services as well as savings, which then affects the production activities again, and the whole cycle repeats itself until the effect is no longer significantly felt.[20]

The second recycling mechanism in which the government shows its 'generosity' to low-income households will immediately increase their income. With the increase in income, households can then increase their spending, and to a lesser extent savings, although this is somewhat dampened by the energy subsidy reduction or carbon tax implementation. This change, however, will directly affect production activities within the country as well as abroad through import demand. This change in production activities then follows a similar path as the first recycling mechanism. A slight difference arises in this mechanism, with a more direct effect to households abroad, due to the existence of remittances, and savings-investment account. Note that for the former, which also applies as well to the first recycling mechanism, changes are felt directly through remittance only if remittances are sent, not received. As to the latter, the change in savings-investment affects production activities both within the country and abroad. Financial transfer between savings-investment in different countries, however, is not affected.[21]

Lastly, the third recycling mechanism is done by reducing indirect taxes, which is effectively the equivalent of giving a subsidy, proportional to the industry size in terms of total output value. The rate of indirect tax reduction, i.e. negative indirect tax, is the same for all industrial sectors within the country although the nominal value of reduction would then differ accordingly. For the case of a carbon tax implementation, this 'assistance' is somewhat dampened for carbon-intensive

[20] The stability of this system has been proven by Leontief through his I-O table which shows that marginal propensity to consume is less than one. Anecdotally, these changes will eventually, literally 'run out of steam'. In which case, a new equilibrium is then achieved.

[21] This is more of a technical limitation of the model than a real world limitation.

industries but could potentially be beneficial to other less-polluting sectors. As for the case of an energy subsidy reduction, this 'assistance' is somewhat dampened only for industries that have their subsidies eliminated, e.g. coal and electricity sectors, but could potentially be beneficial to other sectors. The impact flow to the economy follows a similar pattern as in the first mechanism. However, the magnitude of the impact may significantly differ due to its direct nature in the production activities of commodities. Theoretically, the double-dividend hypothesis, if it exists, should appear more prominently through this mechanism as it supposedly creates a less distortionary tax system in the economy. Whether this holds true or not, running the numbers is required.

5. Concluding Remarks

The IRSA-ASEAN model described here represents a single period equilibrium. None of the arguments in various equations involve lagged variables or expected future variables, so the model is genuinely static. It determines a flow equilibrium based on signals for the current period based only on initial conditions captured in the base year database. As such, the interpretation of the results involves a very simple notion of time, 'long-enough'. Whether that period is short, medium, or long depends on assumptions about elasticities and factor mobility in the model.

As a tool for policy analysis, the IRSA-ASEAN model is more than sufficient to provide a region-wide, bird's-eye view of the economy and gives a unique perspective due to its multi-country nature. It is robust enough to provide useful insights into the economy-wide impact of various policies ranging from, but not limited to, trade, environment, and taxes. Even its static nature can easily be adapted into both inter-temporal and recursive dynamic models given enough additional data, which are unfortunatelywell beyond the scope of this thesis. Nevertheless, the static nature of the IRSA-ASEAN model for short and medium term policy may provide more relevant solution as policy-makers in developing countries are arguably much more interested in the short and medium term gains rather than long term benefits.

Furthermore, another highlight of the IRSA-ASEAN model is its ability to be used as an analytical tool for international policy coordination.The main goal of this modelis to understand the impact of coordinated and non-coordinated policies, i.e. energy subsidy reduction and carbon tax implementation, on the economy and environmental performance of each country within ASEAN. Although, as previously stated, the IRSA-ASEAN model is not limited to the exploration of these issues; its uniqueness lies in the fact that it explores these issues and does so by looking with a region-wide perspective, namely ASEAN. How accurate the model and results it produce willremain to be seen and explored further in otherpapers.

Reference

Abimanyu, A. 2000, “Impact of Agriculture Trade and Subsidy Policy on the Macroeconomy, Distribution, and Environment in Indonesia: A Strategy for Future Industrial Development”, *Developing Economies*, vol. 38, no. 4, pp. 547-571.

Azis, I. J. 2000, “Simulating Economy-Wide Models to Capture the Transition from Financial Crisis to Social Crisis”, *The Annals of Regional Science*, vol. 34, no. 2, pp. 251-278.

Breuss, F. and Tesche, J. 1991, “A CGE Model of Austria: Some Implications of Trade Liberalization”, *Empirica*, vol. 18, no. 2, pp. 135-165.

Chan, N. and Dung, T. K. 2001, *Further Development of CGE Model to Evaluate Tariff Policy in Vietnam*, paper presented at the MIMAP Modelers Conference on 23-28 April 2001, Singapore.

Cororaton, C. and Corong, E. 2006, *Agriculture-Sector Policies and Poverty in the Philippines: A Computable General Equilibrium (CGE) Analysis*, MPIA Working Paper 2006-09, Poverty and Economy Policy (PEP), Manila.

Deardorff, A. V., and Stern, R. M. 1986, *The Michigan Model of World Production and Trade*, Cambridge.

Duraman, H. I. and Asafu-Adjaye, J. 1999, “Short-Run Simulations with a CGE Model of Brunei Darussalam”, in Obben, J. and Ee, T. S. (eds.), *Readings on the Economy of Brunei Darussalam*, Universiti Brunei Darussalam, pp. 72-99.

Fujii, T. and Roland-Holst, D. 2005, *How Does Vietnam’s Accession to the World Trade Organization Change the Spatial Incidence of Poverty and Inequality?*, paper presented at the JICA-UNU-WIDER Meeting on the Impact of Globalization on the Poor in Asia on 25-26 April 2005, Tokyo.

Haaland, J. I. 1990, "Assessing the Effects of EC Integration of EFTA Countries: The Position of Norway and Sweden", *Journal of Common Market Studies*, vol. 28, no. 4, pp. 381-400.

Harris, R. 1984, “Applied General Equilibrium Analysis of Small Open Economies with Scale Economies and Imperfect Competition”, *The American Economic Review*, vol. 74, no. 5, pp. 1016-1032.

Harrison, G. W., Rutherford, T. F., and Wooton, I. 1989, "The Economic Impact of the European Community", *American Economic Review*, vol. 79, no. 2, pp. 288-294.

Hertel, T. W. 1997, *Global Trade Analysis: Modeling and Applications*, Cambridge.

Jaafar, A. H., Al-Amin, A., and Siwar, C. 2008, *A CGE Analysis of the Economic Impact of Output-Specific Carbon Tax on the Malaysian Economy,* paper presented at the 3rd National Conference on Malaysia Economy on 20-22 August 2008, Port Dickson.

Johansen, L. 1960, *A Multi-Sectoral Study of Economic Growth*, Amsterdam.

Karunaratne, N. D. 1998, “Trade Liberalization in Thailand: A Computable General Equilibrium (CGE) Analysis”, *The Journal of Developing Areas*, vol. 32, no. 4, pp. 515-540.

Lee, H. 2008, *The Combustion-Based CO2 Emissions Data for GTAP Version 7 Data Base*, Center for Global Trade Analysis, Purdue University, Cambridge.

Lee, H. and Mensbrugghe, D. 2004, “EU Enlargement and Its Impacts on East Asia”, *Journal of Asian Economics*, vol. 14, pp. 843-860.

Lee, H., Roland-Holst, D., and Mensbrugghe, D. 2004, “China’s Emergence in East Asia under Alternative Trading Arrangements”, *Journal of Asian Economics*, vol. 15, pp. 697-712.

Lewis, J. D. 1991, *A Computable General Equilibrium (CGE) Model of Indonesia,* HIID Series of Development Discussion Papers No. 378, Cambridge.

Li, J. C. 2002, *A 1998 Social Accounting Matrix (SAM) for Thailand*, Trade and Macroeconomic Division Discussion Paper no. 95, International Food Policy Research Institute, Washington, D. C.

McDonald, S., Thierfelder, K., and Robinson, S. 2007, *Globe: A SAM Based Global CGE Model using GTAP Data*, Departmental Working Paper, United States Naval Academy Department of Economics, Annapolis.

Mensbrugghe, D. 2005, *LINKAGE Technical Reference Document*, Development Prospects Group (DECPG), The World Bank, Washington, D. C.

Nielsen, C. P. 2002, *Social Accounting Matrices for Vietnam 1996 and 1997*, Trade and Macroeconomic Division Discussion Paper no. 86, International Food Policy Research Institute (IFPRI), Washington, D. C.

Norman, V. 1989, "EFTA and the Internal European Market", *Economic Policy*, vol. 9, pp. 423-465.

Oktaviani, R., Hakim, D., Sahara, S., and Siregar H. 2007, *The Impact of a Lower Oil Subsidy on Indonesian Macroeconomic Performance, Agricultural Sector and Poverty Incidences: A Recursive Dynamic Computable General Equilibrium Analysis*, MPIA Working Paper 2007-28, Poverty and Economic Policy (PEP), Manila.

Oum, S. 2009, *Income Distribution and Poverty in a CGE Framework: A Proposed Methodology*, Economic Research Institute for ASEAN and East Asia (ERIA) Discussion Paper Series ERIA-DP-2009-18, Jakarta.

Pyatt, G., Round, J. I., and Denes, J. 1984, *Improving the Macroeconomic Data Base: A SAM for Malaysia, 1970*, the International Bank for Reconstruction and Development, Washington, D. C.

Ratha, D. and Shaw, W. 2007, *South-South Migration and Remittances*, the International Bank for Reconstruction and Development, Washington, D. C.

Resosudarmo, B. P. 2002. “Indonesia’s Clean Air Program”, *Bulletin of Indonesian Economic Studies*, vol. 38, no. 3, pp. 343-66.

Resosudarmo, B. P., Ramayandi, A., Yusuf, A. A., and Siyaranamual, M. D. 2008, *Technical Note and Manual for Inter Regional System of Analysis for Indonesia in Five Regions (IRSA-Indonesia5)*, available at http://ceds.fe.unpad.ac.id/ircge/.

Savard, L. 2010, “Scaling Up Infrastructure spending in the Philippines: A CGE Top-Down Bottom-Up Microsimulation Approach, *International Journal of Microsimulation*, vol. 3, no. 1, pp. 43-59.

Scarf, H. E. 1967, “The core of an n-person game”, *Econometrica*, vol. 35, pp. 50–69.

Shoven, J. B. and Whalley, J. 1992, *Applying General Equilibrium,* New York.

Siriwardana, M. and Iddamalgoda, A. 2003, *"Effects of the Asian Economic Crisis on Singapore and Its Policy Responses: A General Equilibrium Analysis*", *Journal of the UNE Asia Centre,* no. 6, Armidale.

Smith, A., and Venables, A. J. 1988, "Completing the International Market in the European Community: Some Industry Simulations", *European Economic Review*, vol. 32, no. 7, pp. 1501-1525.

Warr, P. 2005, "Food Policy and Poverty in Indonesia: A General Equilibrium Analysis", *Australian Journal of Agricultural and Resource Economics*, vol. 49, no. 4, pp. 429-451.

Whalley, J. 1985, *Trade Liberalization among Major World Trading Areas*, Cambridge.

Yusuf, A. 2007, *The Impact of Environmental Policies on Poverty and Income Distribution: An Application of Micro-simulation CGE Model to Indonesia*, Unpublished Ph.D. Thesis, Australian National University, Canberra.

Appendix1. IRSA-ASEAN Model GAMS Syntax

```
$ontext
parameter
aint(c,i,d)             Leontief intermediate coefficient
 aprim(i,d)              Leontief primary factor coefficient
 itxr(i,d)               Indirect tax rate government
 itxm(c,r,d)             Import tariff rate from country r
 itxn(i,d)               Import tariff rate from ROW
ytaxh(h,d)              household income tax rate
strhh(hh,r,h,d)         share of inter-households transfer
strhr(h,d)              share of household income transfers to ROW
apcgr(d)                government propensity to consume
strgrh(h,d,r)           government transfer rate to household
strgrgr(d,r)            inter-government transfers rate
strgrr(d)               government transfer rate to row
strcogr(r,d)            corporate transfer rate to government
strcohh(h,d,r)          corporate transfer rate to households
strcoro(d)              corporate transfer rate to row
strcoco(r,d)            corporate transfer rate to corporate
apcro                   ROW propensity to consume
strrofa(f,d)            ROW share of payment from using factors
strroco(d)              ROW transfer rate to corporate
strrogr(d)              ROW transfer rate to government
strroh(h,d)             ROW transfer rate to households

delprim(f,i,d)          share parameter value-added CES
alpprim(i,d)            shift parameter value added CES
rhoprim(i,d)            parameter of value-added CES

deltrad(c,r,d)          share parameter country-sourcing
alptrad(c,d)            shift parameter country-sourcing
rhotrad(c,d)            parameter of CES country-sourcing

delarm(c,s,d)           share parameter CES Armington
alparm(c,d)             shift parameter CES Armington
rhoarm(c,d)             CES parameter Armington

bdgsh(c,h,d)            household budget share
bdgsgr(c,d)             budget share government
expelas(c,r)            export elasticity

 strco2h(h,d)            share parameter for household revenue recycling

 NXP(i,d)                non-positive output
;
$offtext

variable

*** 1) Variable Declaration

* endogenous variables
 PDOM(c,r)       Producer price at country of origin r
 PQ(c,s,d)       Purchaser price at country of destination d (composite-s)
 PQ_S(c,d)       Price of Import-Dom. composite

 XD(c,s,d)       Domestic-import sourcing (Mod)
 XD_S(c,d)       Domestic-import composite
 XINT_S(c,i,d)   Intermediate composite (import-dom)
 XHOU_S(c,h,d)   Household composite (import-dom)
 XTOT(i,d)       Output
 EH(h,d)         Household disposable income
 XEXP(c,r)       Export demand (Mod)
 XTRAD_R(c,d)    Demand composite over region r
 XFAC(f,i,d)     Demand for factor of production (composite-r)
 XFACRO(f,d)     Demand for factor by ROW
 PFAC(f,d)       Price of factors (composite-r)
 PPRIM(i,d)      Price of value added
 XPRIM(i,d)      Value added
 XTRAD(c,r,d)    Demand of com c from region r by region d

 YH(h,d)         Household total factor income
 YGR(d)          government revenue
 EGR(d)          government expenditure
```

```
 SGR(d)          government saving

 YCO(d)          Corporate revenue
 ECO(d)          Corporate expenditure
 SCO(d)          Corporate saving
 XIMP(c,d)       Total import of com. C

 YRO(d)          Rest of the world revenue
 ERO(d)          Rest of the world expenditure
 SRO(d)          Rest of the world saving

 SH(h,d)         Household saving
 SAV(d)          Aggregate saving
 EXR(d)          Nominal exchange rate

* Exogenous variables
 XINV_S(c,d)     Investment demand (composite-s)
 PFIMP(c,d)      World price of import
 PFEXP(c,r)      World price of export
 XGOR_S(c,d)     Government consumption

* miscellaneous variables
savh(h,d)       Household savings rate
savco(d)        Corporate savings rate
adjsav          Overall savings adj. factor
alpexp(c,r)     Export quantity shifter

 lambda(c,d)     Share investment
 PX              Producer's price index
 TRSAVINV(d,r)   Savings-investment transfer

* ------------------- Carbon Related Variables ------------------------ *
 XCOI(e,i,d)      CO2 Emissions by industry
 XCOH(e,h,d)      CO2 Emissions by household

stx(c,d)         Sales tax rate
cotax(d)         Carbon tax (USD per ton)

 TCTR(d)          Total revenue from carbon tax or subsidy reduction
 TCH(d)           Recycled revenue to household
 TCI(d)           Recycled revenue to industry
 TCG(d)           Recycled revenue to government

alpcarbh(d)      Share of CO2 tax revenue to household
alpcarbi(d)      Share of CO2 tax revenue to industry
alpcarbg(d)      Share of CO2 tax revenue to government

 tco2(d)          Indirect tax reduction rate

* --------- to assist flexible factor market closure ----------------- *

atot(i,d)        top-nest tech. change
 XFACSUP(f,d)     factor supply
 YFAC(f,r)        total factor income
 WDIST(f,i,d)     factor price distortion
;

*** 2) variable initialization
 PDOM.L(c,r) = PDOM0(c,r);
 PQ.L(c,s,d) = PQ0(c,s,d);
 PQ_S.L(c,d) = PQ_S0(c,d);

 PXCINT.L(i,d) = PXCINT0(i,d);
 XD.L(c,s,d) = XD0(c,s,d);
 XD_S.L(c,d) = XD_S0(c,d);

 XINT_S.L(c,i,d) = XINT_S0(c,i,d);
 XHOU_S.L(c,h,d) = XHOU_S0(c,h,d);
 XTOT.L(i,d) = XTOT0(i,d);
 EH.L(h,d) = EH0(h,d);
 XEXP.L(c,r) = XEXP0(c,r);
 XTRAD_R.L(c,d) = XTRAD_R0(c,d);
 XFAC.L(f,i,d) =  XFAC0(f,i,d);
 XFACRO.L(f,d) = XFACRO0(f,d);
 PFAC.L(f,d) =  PFAC0(f,d);
 PPRIM.L(i,d) = PPRIM0(i,d);
 XPRIM.L(i,d) = XPRIM0(i,d);
```

```
 XTRAD.L(c,r,d) = XTRAD0(c,r,d);

 YH.L(h,d) = YH0(h,d);
 YGR.L(d) = YGR0(d);
 EGR.L(d) = EGR0(d);
 SGR.L(d) = SGR0(d);

 YCO.L(d) = YCO0(d);
 ECO.L(d) = ECO0(d);
 SCO.L(d) = SCO0(d);
 XIMP.L(c,d) = XIMP0(c,d);

 YRO.L(d) = YRO0(d);
 ERO.L(d) = ERO0(d);
 SRO.L(d) = SRO0(d);
 SH.L(h,d) = SH0(h,d);
 SAV.L(d) = SAV0(d);
 XINV_S.L(c,d) = XINV_S0(c,d);
 EXR.L(d) = EXR0(d);

 PFIMP.L(c,d) = PFIMP0(c,d);
 PFEXP.L(c,r) = 1;

 XGOR_S.L(c,d) = XGOR_S0(c,d);

 savh.L(h,d) = savh0(h,d);

 savco.L(d) = savco0(d);
 adjsav.L = 1;

 lambda.L(c,d) = PQ_S0(c,d)*XINV_S0(c,d)
               / SUM(cc,PQ_S0(cc,d)*XINV_S0(cc,d));
 PX.L = 1;
 alpexp.L(c,r) =  alpexp0(c,r);

 TRSAVINV.L(d,r) = TRSAVINV0(d,r);

 XCOI.L(e,i,d) = XCOI0(e,i,d);
 XCOH.L(e,h,d) = XCOH0(e,h,d);

 stx.L(c,d) = 0;
 tco2.L(d) = 0;

 TCTR.L(d) = 0;
 TCH.L(d) = 0;
 TCI.L(d) = 0;
 TCG.L(d) = 0;

 cotax.L(d) = 0;
 alpcarbh.L(d) = 0;
 alpcarbi.L(d) = 0;
 alpcarbg.L(d) = 0;

 atot.l(i,d) = 1;
 XFACSUP.L(f,d) = XFACSUP0(f,d);
 YFAC.L(f,r) = YFAC0(f,r);
 WDIST.L(f,i,d) = WDIST0(f,i,d);

* ---------------------------------------------

equations

*** 3) equation declaration

* PRODUCTION SECTORS

* Production of output
 e_xtot(i,d)              zero profit condition
 e_xint_s(c,i,d)          intermediate input demand function
 e_xprim(i,d)             primary input demand function

* Production of primary input
 e_xfac(f,i,d)            demand for factors or production
 e_pprim(i,d)             zero profit condition

* EXPORT-IMPORT
```

```
* Import from origins r to regional market
 e_xtrad(c,r,d)           demand for commodities from country r in country d
 e_pq_dom(c,d)            price of region composite in country d

* Import from abroad to region d
 e_xd(c,s,d)              Armington condition for country d
 e_pq_s(c,d)              zero profit condition for import from abroad at country d
 e_pq_m(c,d)              tariff for country import

* Export
 e_xexp(c,r)              export demand

* Market Clearing Condition
 e_ximp(c,d)              foreign import market clearing (Mod)
 e_xtrad_r(c,d)           market clearing for domestic demand at region d
 e_xd_s(c,d)              market clearing for commodity c at region d

* INSTITUTIONAL BEHAVIOR (Household, Governments, Corporate)

* Factors
 e_yfac(f,r)              total factor income

* Households
 e_yh(h,d)                household income
 e_eh(h,d)                household disposable income for consumption
 e_xhou_s(c,h,d)          household demand: LES model

* Government
 e_ygr(d)                 income of government
 e_egr(d)                 expenditure of government
 e_xgor_s(c,d)            government demand

* Corporate sector
 e_yco(d)                 income of corporate sector
 e_eco(d)                 expenditure of corporate sector

* INVESTMENT
 e_sh(h,d)                household saving
e_sco(d)                 savings of corporate sector
 e_sav(d)                 aggregate saving
 e_xinv_s(c,d)            investment demand
 e_px                     producer's price index

* MARKET CLEARING
 e_pfac(f,d)              market clearing for factors
 e_pdom(c,r)              market clearing for commodities

* REST OF THE WORLD
 e_yro(d)                 payment outflow
 e_ero(d)                 payment inflow
 e_sro(d)                 Balance of Payment

* CO2 EMISSIONS
e_xcoi(e,i,d)            co2 emissions by industry
e_xcoh(e,h,d)            co2 emissions by households
e_stx(e,d)               carbon tax to sales tax

e_tctr(d)                total revenue from carbon tax or subsidy reduction
e_tctrh(d)               recycled revenue to household
e_tctri(d)               recycled revenue to industry
e_tctrg(d)               recycled revenue to government

e_tci(d)                 indirect tax reduction
;

*** 4) equation statement

* -------------------------- equations ------------------------------ *

* PRODUCTION SECTORS

* Production of Output
** demand of all inputs
 e_xint_s(c,i,d)..   XINT_S(c,i,d) =e= atot(i,d)*aint(c,i,d)*XTOT(i,d);
 e_xprim(i,d)..  XPRIM(i,d) =e= atot(i,d)*aprim(i,d)*XTOT(i,d);

** zero profit of production
```

```
 e_xtot(i,d)..
  (1-itxr(i,d)+tco2(d))*PDOM(i,d)*XTOT(i,d) =e=
  PPRIM(i,d)*XPRIM(i,d) + SUM(c,(1 + stx(c,d))*PQ_S(c,d)*XINT_S(c,i,d));

* Product of Primary Input
* demand for factors of production
 e_xfac(f,i,d)$XFAC0(f,i,d)..
    XFAC(f,i,d) =e=
alpprim(i,d)**(-rhoprim(i,d)/(1+rhoprim(i,d)))
     * XPRIM(i,d)
     * (delprim(f,i,d)**(1/(rhoprim(i,d)+1))
     * (( (WDIST(f,i,d)*PFAC(f,d))/PPRIM(i,d) )
     ** (-1/(rhoprim(i,d)+1)) ));

** zero profit condition of primary inputs
 e_pprim(i,d)$XP(i,d)..
  PPRIM(i,d)*XPRIM(i,d) =e= SUM(f,(WDIST(f,i,d)*PFAC(f,d))*XFAC(f,i,d));


* ------------------------------------------------------------------ *

* EXPORT-IMPORT

** Import from origins r to country market
*** demand for commodities from country r in country d
 e_xtrad(c,r,d)..
    XTRAD(c,r,d) =e=
alptrad(c,d)**(-rhotrad(c,d)/(1+rhotrad(c,d)))
     * XTRAD_R(c,d)
     * (deltrad(c,r,d)**(1/(rhotrad(c,d)+1))
     * ((((1+itxm(c,r,d))*PDOM(c,d))/PQ(c,"dom",d)) ** (-1/(rhotrad(c,d)+1))));

*** price of region composite in country d
 e_pq_dom(c,d)..
      PQ(c,"dom",d)*XTRAD_R(c,d) =e=
            SUM(r,(1+itxm(c,r,d))*PDOM(c,d)*XTRAD(c,r,d));

** Import from abroad to country d
*** Armington condition for country d
 e_xd(c,s,d)..
    XD(c,s,d) =e=
alparm(c,d)**(-rhoarm(c,d)/(1+rhoarm(c,d)))
     * XD_S(c,d)
     * (delarm(c,s,d)**(1/(rhoarm(c,d)+1))
     * (( PQ(c,s,d)/PQ_S(c,d) ) ** (-1/(rhoarm(c,d)+1))));

*** zero profit condition for import from abroad at country d
 e_pq_s(c,d)..
         PQ_S(c,d)*XD_S(c,d) =e= SUM(s,PQ(c,s,d)*XD(c,s,d));

*** tariff for regional import
 e_pq_m(c,d)..   PQ(c,"imp",d) =e= (1 + itxn(c,d))*PFIMP(c,d)*EXR(d);

* Export
*** export demand at the national market
 e_xexp(c,r)$XEXP0(c,r)..
    XEXP(c,r) =e= alpexp(c,r)*[(PDOM(c,r)/EXR(r))/PFEXP(c,r)]**(-expelas(c,r));

* Market Clearing Condition
** Foreign import market clearing
 e_ximp(c,d)..
     XIMP(c,d) =e= XD(c,"imp",d);

** Market clearing for domestic demand at country d
 e_xtrad_r(c,d)..
   XTRAD_R(c,d) =e= XD(c,"dom",d);

** Market clearing for commodity c at country d
 e_xd_s(c,d)..
   XD_S(c,d) =e= SUM(i,XINT_S(c,i,d)) + SUM(h,XHOU_S(c,h,d))
              + XGOR_S(c,d)+ XINV_S(c,d);

* ------------------------------------------------------------------ *

* INSTITUTIONAL BEHAVIOR (Households, Government, Corporate)

* Total Factor Income
```

```
 e_yfac(f,r)..
   YFAC(f,r) =e= SUM(i,WDIST(f,i,r)*PFAC(f,r)*XFAC(f,i,r));

* Households
** household income
 e_yh(h,d)..
  YH(h,d) =e=  SUM((r,f),SFACHH(r,h,d,f)*YFAC(f,r))
           + 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-ytaxh(hh,r))*YH(hh,r)))
           + strco2h(h,d)*TCH(d);

** household disposable income for consumption
 e_eh(h,d)..
   EH(h,d) =e= (1-SUM(hh,SUM(r,strhh(hh,r,h,d)))
              - strhr(h,d))
              * (1-savh(h,d)) * (1-ytaxh(h,d)) * YH(h,d);

** household demand
 e_xhou_s(c,h,d)..
    (1 + stx(c,d))*PQ_S(c,d)*XHOU_S(c,h,d) =e=
         + bdgsh(c,h,d)*EH(h,d)
;

* Regional Government
** income of regional government
 e_ygr(d)..
     YGR(d) =e= SUM(i,(itxr(i,d)-tco2(d))*PDOM(i,d)*XTOT(i,d))
              + SUM(r,strcogr(d,r)*YCO(r))
              + SUM((r,f),SFACGR(r,d,f)*YFAC(f,r))
              + SUM(h,ytaxh(h,d)*YH(h,d))
              + SUM(c,SUM(r,itxm(c,r,d)*PDOM(c,d)*XTRAD(c,r,d)))
              + SUM(c,itxn(c,d)*PFIMP(c,d)*XIMP(c,d)*EXR(d));

** expenditure of regional government
 e_egr(d)..
    EGR(d) =e= (1-(SUM(h,SUM(r,strgrh(h,d,r)))))
               * YGR(d) + TCG(d) - SGR(d);

** government demand
 e_xgor_s(c,d)..
    PQ_S(c,d)* XGOR_S(c,d) =e= bdgsgr(c,d) * EGR(d);

* Corporate sector
* income of corporate sector
 e_yco(d)..
     YCO(d) =e= SUM((r,f),SFACCO(r,d,f)*YFAC(f,r))
              + SUM(r,strcoco(d,r)*YCO(r));

* expenditure of corporate sector
 e_eco(d)..
     ECO(d) =e=  (SUM(r,strcogr(r,d))
              + SUM(h,SUM(r,strcohh(h,d,r)))
              + SUM(r, strcoco(r,d)) + strcoro(d)) * YCO(d);

* ---------------------------------------------------------------------- *

* INVESTMENT

* household saving
 e_sh(h,d)..     SH(h,d) =e= savh(h,d)*(1-ytaxh(h,d))*YH(h,d);

* savings of corporate sector
 e_sco(d)..      SCO(d) =e= adjsav*savco(d)*YCO(d);

* aggregate saving
 e_sav(d)..
     SAV(d) =e= SUM(h,SH(h,d)) + SGR(d) + SCO(d)
          + EXR(d)*SRO(d) + SUM(r,TRSAVINV(d,r));

* investment demand
 e_xinv_s(c,d)..
    PQ_S(c,d)*XINV_S(c,d) =e= lambda(c,d)
                           * (SAV(d) - SUM(r,TRSAVINV(r,d)));

* producer's price index
```

```
 e_px..          PX =e= SUM((i,d), wgtpx(i,d)*PDOM(i,d));

* ------------------------------------------------------------------- *

* MARKET CLEARING

* market clearing for factors
 e_pfac(f,d)..
   SUM(i,XFAC(f,i,d)) +  XFACRO(f,d) =e= XFACSUP(f,d);


* market clearing for commodities
 e_pdom(c,r)$XP(c,r)..    XTOT(c,r) =e=
                  SUM(d,XTRAD(c,r,d)) + XEXP(c,r);

* ------------------------------------------------------------------- *

* REST OF THE WORLD

* BALANCE OF PAYMENT

* payment outflow (in $)
 e_yro(d)..
     YRO(d) =e= SUM(c,PFIMP(c,d)*XIMP(c,d)*EXR(d))
          + SUM(h,SUM(hh,SUM(r, strhh(h,r,hh,d)*(1-savh(hh,d))*(1-
ytaxh(hh,d))*YH(hh,d))))
          + SUM((c,r),PDOM(c,d)*XTRAD(c,r,d)$(XTRAD0(c,r,d) ne XTRAD0(c,d,r)))
          + SUM(r,TRSAVINV(r,d));

* payment inflow (in $)
 e_ero(d)..
      ERO(d) =e= SUM(h,SUM(hh,SUM(r, strhh(h,d,hh,r)*(1-savh(hh,r))*(1-
ytaxh(hh,r))*YH(hh,r))))
          + SUM((c,r),PDOM(c,d)*(XTRAD(c,d,r)$(XTRAD0(c,r,d) ne XTRAD0(c,d,r))))
          + SUM(c,PDOM(c,d)*XEXP(c,d))
          + SUM(r,TRSAVINV(d,r))
          + SRO(d);

* Balance of Payment
 e_sro(d)$(YRO0(d) ne YRO0('IDN'))..       YRO(d) =e= ERO(d);

*-------------------------------------------------------------------------
* CO2 EMISSIONS

* CO2 emissions
e_xcoi(e,i,d)..    XCOI(e,i,d) =e= cci(e,i,d)*XINT_S(e,i,d);
e_xcoh(e,h,d)..    XCOH(e,h,d) =e= cch(e,h,d)*XHOU_S(e,h,d);

e_stx(e,d)..       stx(e,d) =e= cotax(d)*[(SUM(i,XCOI(e,i,d))
                                    + SUM(h,XCOH(e,h,d)))]
                              / [PQ_S(e,d)*(SUM(i,XINT_S(e,i,d))
                                    + SUM(h,XHOU_S(e,h,d)))];

e_tctr(d)..      TCTR(d) =e= SUM(c,stx(c,d)*PQ_S(c,d)*SUM(h,XHOU_S(c,h,d)))
                           + SUM(c,stx(c,d)*PQ_S(c,d)*SUM(i,XINT_S(c,i,d)));

e_tctrh(d)..     TCH(d) =e= alpcarbh(d) * TCTR(d);

e_tctri(d)..     TCI(d) =e= alpcarbi(d) * TCTR(d);

e_tctrg(d)..     TCG(d) =e= alpcarbg(d) * TCTR(d);

e_tci(d)..       tco2(d)*SUM(i,PDOM(i,d)*XTOT(i,d)) =e= TCI(d);

* ---------------------- end of equations ---------------------------- *

display cotax.L, stx.L ,XCOI.L, XCOH.L, XINT_S.L, XHOU_S.L, TCTR.L
;

* --------------------------- closure ------------------------------- *
 PX.FX = PX.L;
 PFIMP.FX(c,d) = PFIMP.L(c,d);
 PFEXP.FX(c,r) = PFEXP.L(c,r);
savh.fx(h,d) = savh.L(h,d);
savco.fx(d) = savco.L(d);
adjsav.fx = adjsav.L;
lambda.FX(c,d) =  lambda.L(c,d);
```

```
 XFACRO.FX(f,d) = XFACRO.L(f,d);
itxr.fx(i,d) = itxr0(i,d);
itxm.fx(c,r,d) = itxm0(c,r,d);
itxn.fx(c,d) = itxn0(c,d);
alpexp.fx(c,r) =  alpexp.L(c,r);
XFACSUP.fx(f,d) = XFACSUP0(f,d);
WDIST.fx(f,i,d) = WDIST0(f,i,d);
 SRO.FX(d) = SRO.L(d);

atot.fx(i,d) = atot.l(i,d);

TRSAVINV.fx(d,r) = TRSAVINV.l(d,r);

* ------------------ carbon tax closure ------------------------------ *
cotax.fx(d) = cotax.l(d);
stx.fx(c,d) = stx.l(c,d);
stx.lo(e,d) = -INF;
stx.up(e,d) = +INF;

alpcarbh.fx(d) = alpcarbh.l(d);
alpcarbi.fx(d) = alpcarbi.l(d);
alpcarbg.fx(d) = alpcarbg.l(d);

 SGR.FX(d) = SGR.L(d);

* ------------- Land & capital is immobile -------------------------- *

 set fx(f) fixed factor / FFCAPITAL, FFLAND, FFNATLRES /;

 XFAC.FX(fx,i,d)$XFAC.L(fx,i,d) = XFAC.L(fx,i,d);
 WDIST.UP(fx,i,d)$XFAC.L(fx,i,d) = +INF;
 WDIST.LO(fx,i,d)$XFAC.L(fx,i,d) = -INF;
 XFACSUP.UP(fx,d) = +INF;
 XFACSUP.LO(fx,d) = -INF;
PFAC.fx(fx,d) = PFAC.L(fx,d);

* ------------------ unemployed labor ------------------------------ *

 set fl(f) unemployed labor / FFUNSKLAB, FFSKLAB /;
 XFACSUP.FX(fl,d) = XFACSUP.L(fl,d);

* ------------------------ end of closure ----------------------------*

* ------------- variable not in the model is zero -------------------- *
 PPRIM.FX(i,d)$NXP(i,d) = 1;
 PDOM.FX(c,r)$NXP(c,r) = 1;
 XFAC.FX(f,i,d)$(not XFAC0(f,i,d)) = 0;
 XEXP.FX(c,r)$(not XEXP0(c,r)) = 0;

* ---------------------------------------------------------------------- *
 option iterlim = 0;
 option limrow = 10000;

*** 6) Model statement

model IRCGEv1
 /
 e_xprim
 e_xint_s
 e_xtot
 e_xfac
 e_pprim
 e_xtrad
 e_pq_dom
 e_xd
 e_pq_s
 e_pq_m
 e_xexp
 e_ximp
 e_xtrad_r
 e_xd_s
 e_yfac
 e_yh
 e_eh
 e_xhou_s
 e_ygr
 e_egr
```

```
 e_xgor_s
 e_yco
 e_eco
 e_sh
 e_sco
 e_sav
 e_xinv_s
 e_px
 e_pfac
 e_pdom
 e_yro
 e_ero
e_xcoi
e_xcoh
e_stx
e_tctr
e_tctrh
e_tctri
e_tctrg
e_tci
 e_sro
 /;

solve IRCGEv1 using MCP;
```