The Impact of Biofuels Policy on Trade and Food Security in Developing Countries

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Abstract

We developed Dynamic Inter Regional Computable General Equilibrium (IR-CGE) for Energy and Agriculture Model that incorporates geographic features into CGE. Within the context of comparative advantage we demonstrate how the biofuel policy impact on trade and food security. We find that biofuel policy may benefit for exporters countries which mostly are developing countries and cost for importers countries . In term of geographical analysis, European Union may trading with neighbor country and independent for biofuel commodities from developing countries. Meanwhile, food security issues in developing countries may lead more fluctuated price in agriculture price than in developed countries; in supply side trade liberalization may increase in welfare export and output accordingly.

Keywords: energy policy, recursive dynamid, new trade theory

1. Introduction

In developing economies malnutrition, environmental deteriorating, increasing land degradation, and vulnerabilities agricultural communities are still crucial concern addressing sustainable development. In terms of sustainable development, sustainable agriculture is profound as a leading sector which converge ecological, economic, political, and social condition as a pathways to sustainability (Thompson-Scoones , 2009) .On the other hand, the debate between fuel vs food security has emerged as a profound issue for aca-

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demic and decision makers to assess cost and benefit between bio-energy and food security. Msangi, et.al (2007) reported that increase of bio-energy crop production will encounter binding environmental constraint such as in India, China, and Sub Saharan Africa. Melilo, et.al (2009) noticed that expansion of bio-fuels production may increase the fraction of land to meeting demand for food and bio-fuels at the expense of natural ecosystems in Brazil, the Guinean forest of West Africa, Madagascar, the Indo-Burma, forest of the Philippines, Malaysia, and Indonesia. In terms of food security, increased bio-fuel production because of market driven forces may have significant impacts on agricultural markets including world prices, production, trade flows, and land use. Biofuel would impact of potential increases in food price on low-income groups as well as loss of biodiversity due to increased of land use conversion (Koizumi-Ohga (2007), Banse, et.al (2008), Fischer, et.al (2009)). European Union is one of the regions whose strongest motivation and policy to use energy from renewable sources targets up to 20 % share of renewables including bioenergy in total energy use in 2020 and additionally imposes a 10 % minimum share of renewable energy in transport. According to Kretschmer-Peterson (2009b), this policy rely on imports in order to meet its bio fuels policy target. The prominent partner which has been trading for biofuel commodities between European Union and other region are Brazil, Indonesia, and Malaysia. According to Altieri (2009) increased in demand for biofuels in United States and the European Union have a profound impact on pattern of global agricultural production and land use. He emphasized as long as Brazil produced sugarcane and soybean for biofules had converted forest land to agricultural land by factor of 57 since 1961 until now. Officially Brazil government has planned to respond the global energy market which convert of forest land to agriculture land five fold increase to meet for demand of biofuel energy in the future. Regarding those issues, our paper contribution is less than comprehensive and theoretical underpinning, we prefer empirically to vindicate that increasing biofuel policies would lead dilemmatic problem for developing countries in order to assess trade off between fuel vs food, intuitively we hypothesised that developing countries may severely decrease in welfare rather than developed countries which mostly depend on agriculture and fossil product. To explore these phenomena, we followed Eaton-Kortum (2002) works to support new trade theory with competitive markets, no involving fixed cost, and no monopoly rent. Another reason why we use their procedure we prefer to make simplification for the calibration and permit the use of large scale of general equilibrium into the analysis of those phenomenon, otherwise for monopolistic competition this research need more space to scrutinize, although Melitz (2003) and Balistreri,et.al (2010) had conducted this study, mostly of them are investigated for general trade and industrial organization issues, the energy and agriculture sector need more contemplation to study. The basic facts which not strongly grips in conventional international trade theories that we figure out with our Computable General Equilibrium (CGE) model are a) in long run trade diminishes with distance, European Union prefer trading with neighbor country rather than farther country. This fact may lead that European Union intend to independent for biofuel production and fossil production from developing countries, (b) developing countries gains in trade, therefore the biofuel policy may decrease welfare in the long run for importers and increase welfare for exporters; (b) Effects on food and fuel prices, are crucial concern to be concern in terms of income especially for developing countries. The gentile research with this paper has conducted by various author such as the study of biofuel policy impact on agricultural market price by Banse, et.al (2008) , on land conversion by Taheripour, et.al (2010), on land conversion and environment by Britz-Hertel (2009), and on economic and environment by Kretschmer-Peterson (2009b). Unfortunately, there is another issues to be concern with assessment between fuel vs food debate, therefore we try to fulfill this study to quantify whether the impact of biofuel policy on the trade and food security. Mostly of those author assess food security in term of agriculture structure and production, mandates of biofuel, and target emission which impact on welfare and environment to reducing emission. In order to fill another perspective of these issues, it would be interesting if we bridging those gap to developed CGE Model to assess dynamically between food vs fuel security debate with new trade theory.

2. Methodology

The Computable General Equilibrium (CGE) model which conducted in this paper based on dynamic recursive CGE. Recursive dynamic defined that saving and total consumption are fixed shares of income and consumers, therefore consumers do not change in by certain of magnitude on saving and expectation of future return investment and consumption. Simply explanation, recursive model is a static model which run recursively attached dynamically by investment and capital accumulation path.

Basically CGE model is the optimization model which maximize utility subject to budget constraint which is,

$$U = \left[\sum_{t=0}^{T} \left(\frac{1}{1+\rho} \right)^t C_n^{1-\theta} \right]^{\frac{1}{1-\theta}} \quad (1)$$

Equation (1) explain that representative agent in each region maximizes the utility function subject to a budget constraint, technology and the evolution of capital stock in the economy. Those agent endowed with initial stock of capital, labor, land, and energy resources. Region represented by r across the world and t is time. C_{rt} is aggregate consumption in region r on time t, ρ is a time preference by discount rate, θ is the inverse of the elasticity of inter temporal substitution and T is the terminal period.

The budget constraint of those utility maximization defined as the balance of income and expenditure over the horizon as follows,

$$\sum_{t=0}^{T} p_{rt}^C C_{rt} = \sum_{t=0}^{T} w_{rt} \bar{L}_{rt} + p_{rt}^K K_{r0} + p_{rt}^A \Lambda_{r0} + \sum_{t=0}^{T} \sum_{e} p_{ert}^R \bar{R}_{ert} - p_{T+1} K_{T+1} \quad (2)$$

where p_{rt}^C is the price of aggregate consumption in region r at time t, w_{rt} is the wage rate. $\bar{L}_{rt}$ is the labor endowment. p_{r0}^{Λ} is the initial price of a unit land and Λ_{r0} is land endowment. p_{r0}^K is the initial price of a unit of capital, K_{T+1} is the initial stock of capital, p_{ert}^R is the rate of return energy resource in energy sector e (coal, gas, and oil), $\bar{R}_{ert}$ is the energy resource supply, p_{T+1} is the price of post terminal capital and is the stock of capital in period T + 1. All those prices discounted by interest rate as present value of prices.

At each period t, imbalance in a regions budget constraint accounts for capital flows represented as real assets endogenously. Capital flows are mobile between region which mean that balance of payment require the capital flows to be equal to the differences between aggregate expenditure (private and public consumption and investment) and aggregate income (returns to labor, capital, land, energy resources and tax revenue). This conditions represent by,

$$kf_n = p_{rt}^C + p_{rt}^t t_{rt} - \left(w_{rt} \bar{L}_{rt} + \lambda_{rt} \Lambda_{rt} + r_{rt}^K + \sum_{e} p_{ert}^R \bar{R}_{ert} \right) \quad (3)$$

where kf_{rt} is the capital flow to region r at time t, p^t_{rt} is the price of a unit of investment and r^K_{rt} is the capital rate of return. This equation mean that if one country has current account deficit, there must be a compensating current account surplus in other countries. This condition has implication is that every region which has excess of aggregate expenditure over aggregate income today must be compensate in the future so that there is no net change in indebtedness over the model horizon. Therefore, the budget constraint may represent as shown below,

$$p^C_{rt}C_{rt} + p^I_{rt}I_{rt} + kf_{r,t+1} = w_{rt}\bar{L}_{rt} + \lambda_{rt}\Lambda_{rt} + r^K_{rt} + \sum_e p^R_{ert}\bar{R}_{ert} + (1+i)kf_{rt} \quad (4)$$

Physical capital in our CGE models through the creation of new capital from investment regarding a constant depreciation rate at each period. The capital accumulation equation shown as,

$$K_{r,t+1} = (1-\delta)K_{rt} + I_{rt} \quad (5)$$

where δ represent the depreciation rate. Eventually, we represent as a mathematical programming where maximization of Eq. (1) subject to Eq. (4) and (5) which is initial zero capital flow such that first order condition:

$$\left(\frac{1}{1+\rho}\right)\frac{\partial U(C_{rt})}{\partial C_{rt}} = p_{rt} \quad (6)$$

$$(1-\delta)p^K_{r,t+1} + r^K_{rt} = p^K_{rt} \quad (7)$$

$$p_{rt} = (1+i)p_{r,t+1} \quad (8)$$

where p_t represent the price of aggregate output, is the price of one unit capital stock at period t and $p^K_{r,t+1}$ is the price of unit of capital stock at period t+1. Food Security Measurement. We employed methodological to measure food security according Sharma (1992). Sharma (1992) defined food security is adequacy food at the global level and an effectiveness of trading system to ensure adequate supplies for food deficit countries. Addressing assessment for household security index which we employed to connect with our CGE Model according to Sharma (1992) are production food, export earning, spatial price differentials, degree of deviation per capita agricultural production trend, purchasing power parity, budget allocation for target income transfer (subsidies) and food price inflation relevant for low income households. We prefer using particular indicators to conducted this analysis those are production food, spatial price differential, purchasing power parity, and price inflation. These chosen indicators due to data availability regarding to our CGE model, we hope that these indicator are sufficient to assess food security although these indicators are too aggregative in term of macro economics assessment, regarding to Food Balance Sheet provides by FAO these indicator seems useful to measure food security.

MCP Formulation. As actually implemented according to eq (1) eq (8) those optimization programming is converted into market equilibrium formulation using Mixed Complemetarity Problem (MCP) algorithm, and solve numerically using PATH solver of the General Algebraic Modeling Systems (GAMS v. 23,6 2010) with Mathematical Programming System for General Equilibrium Modeling (MPSGE) written by Thomas Rutherford. In MCP formulation Arrow-Debreu equilibrium described by three classes of equations: the zero profit, market clearance, and income expenditure balance. The zero profit conditions means that economics profit should be equal to zero in equilibrium for any sector that produces a positive quantity of output or vice versa. This definition given by relation as follows,

$$profit \ \geq \ 0; \ output \ \times \ profit \ = \ 0 \tag{9}$$

The market clearance condition implies that a positive price exist for any good with supply less than or equal to demand, or the price will be zero if the good has an excess of supply, given by the relations,

$$demand - supply \ \geq \ 0; price \ \geq \ 0; price \ \times (demand - supply) \ = \ 0 \tag{10}$$

and, the last conditions is the market balance conditions thereby that total expenditure should be equal to the total value of endowments for each agents in the economy.

$$\sum_{i=1}^{r} expenditure_t = \sum_{i=1}^{r} income_t \tag{11}$$

This condition should be satisfied dynamically both inter temporally and over the life time. Inter temporally for each agent current income plus borrowing should equal current expenditure plus saving. During this over time the present value of lifetime income agents should be equal to present value of all future expenditures.

Geographic Feature in CGE Model. Since Krugman (1991) revive the role of geography and Eaton-Kortum (2002) provided empirical finding of new trade theory with competitive market assumptions whereas Krugman (1991) analyzed with monopolistic competition. In term of those issues our CGE model elaborated geographic term into Armington equation. We calculated geogaphic term according to Rutherford (2008) the average distance between region r and s,

$$D_{rs} = \sum_{c_r \in X} \sum_{c_r \in X_s} \theta_{c_r} \theta_{c_s} d_{c_r,c_s} \tag{12}$$

where X_r is the set of cities in region r; θ_{c_r} the fraction of total city population in region r which resides in city c; $d_{c_r c_s}$ the great circle distance between cities c in region r and city c in region s. Calculated on the basis of a great circle approximation. The distance calculation covert from latitude and longitude information to (x,y,z) coodinates on a unit sphere by $x_c = cos(ln_c)cos(lat_c), y_c = sin(ln_c)cos(lat_c), z_c = sin(lat_c)$. Those equation then used to compute into equations (13):

$$s_{c_r,c_s} = \sqrt{(x_{c_r} - x_{c_s})^2 + (y_{c_r} - y_{c_s})^2 + (z_{c_r} - z_{c_s})^2} \tag{13}$$

afterwards, from equation (13) line segment determines the great-circle distance by given this equation,

$$d_{c_r,c_s} = 2tan^{-1}\left(\frac{s_{c_r,c_s}/2}{\sqrt{1-(s_{c_r,c_s}/2)^2}}\right) x3959 \tag{14}$$

where 3959 is the radius of the earth in miles.

3. Data

Database which employed in the model based on the ultimate GTAP databases which is GTAP7 with base year 2004. The GTAP 7 consists of 113 regions around the world for all 57 commodities for a single year 2004 as base year data. In GTAP 7, the bioenergy data has included for first generation of biofuels, unfortunately still aggregated in commodity food processing (ofd) sector and chemicals rubber and plastics (crp) sector for ethanol sector, and vegetable and oilseeds (vf and osd) sector for biodesel sector. To disaggregate those sector in the Social Accounting Matrix (SAM) requires correctly detailed information on where biofuel production is included in the SAM especially for input uses and biofuels trade. For further study we strongly encourage to obtain preferably detailed information to disaggregated for biofuels sector in the GTAP SAM to get more intuitively for analyzing biofuels policy. For this study we aggregated the regions from 113 to 18 regions which are Australia and New Zealand, United States, Canada, Japan, Indonesia, Malaysia, Thailand, India, China, Latin America Countries, Brazil, European Union, Former Soviet Union, Developed Asia, Middle Eastern, Africa, and Rest of the World. The commodities which were we aggregated from 57 sector to 31 sector consists of paddy rice, wheat, grains, vegetable fruits nuts, oil seed, sugarcane, sugarbeet, plant based fibre, crops, bovine cattle meat product, animal product, raw milk, other agriculture product, processed rice, sugar, bovine meat product, meat product, vegetables oil, other food product, beverages and tobacco, energy intensive industries, other energy intensive, transport, water transport, air transport, other services, coal, petroleum and coal products, crude oil, natural gas, electricity, and saving goods.

4. Result and Discussion

We consider a 31-year model horizon, defined over the period of 2004 2035. We refer to trade liberalization according to Free Trade Agreement (FTA) between ASEAN countries (Indonesia, Malaysia, Thailand) and European Union (EU). We deliberately chose those countries to elaborate the FTA between ASEAN and EU in the future which define that Biofuels product are agriculture product (Annex 1 of the WTO Agreement in Agriculture (AoA). Paragraph 31 (iii) of Doha Development Agenda), these scenario also imposed both on India and Brazil. Regarding those agreement we reduce the tariff for the Biodiesel and Ethanol material from 90% - 97% on import tariff. For third counterfactual scenario we conducted the biofuel mandates in European Union by 10% in order to analyzed biofuel target as a share of renewable energy in total final energy consumption. Although our model not explicitly show to address those issues, we implicitly calculate the share of production and demand of biofuel and ethanol energy from GTAP-BIO data. In GTAP-BIO we obtained each share of biofuel production and trade, therefore we have information about total demand for biofuel commodities.

Macro Economic Indicators. In term of Gains of Trade the countries whose benefit are Malaysia and Indonesia than any countries due to biofuel

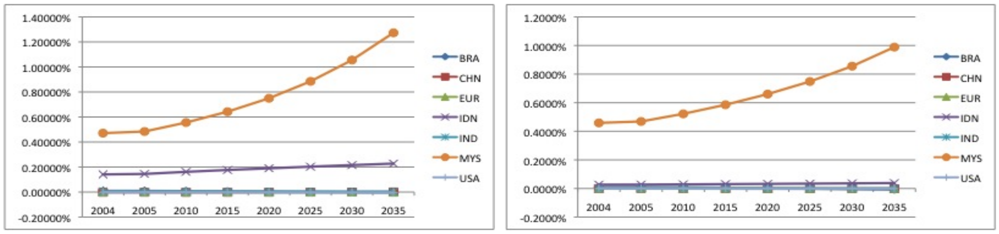

Figure 1: Percentage Change of Hicksian Welfare Index - Scenario 1 and 2

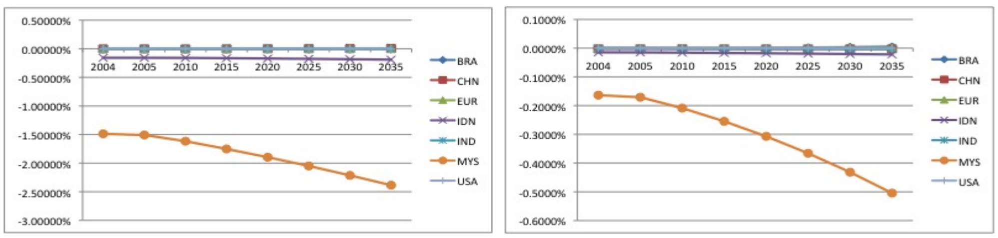

Figure 2: Percentage Change of Technology and Geography - Scenario 1 and 2

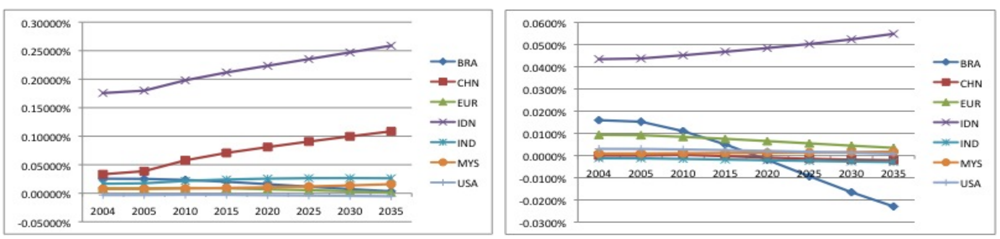

Figure 3: Percentage Change of Demand for Fossil Fuel Energy- Scenario 1 and 2

trade with European Union. The total maximum welfare in between 0 - 1.2%, the maximum welfare reached by Malaysia (1% 1.2% of total welfare), followed by Indonesia between 0.03% - 0.02%. This result is an opposite than Kretschmer-Peterson (2009b) where the Biofuel Policy would decrease -2% in 2020 relative to the BAU (Busines as Usual) scenario. This result, obviously true, because EU relied on those countries as the import source of Biofuel and Bioethanol to meet for biofuel demand, thereby the increasing biofuel policy in EU would lead EU import more from those countries as required to replace fossil fuel energy. Another discussion of the gains from trade has brought up the question in the literature is the roles of geography and technology in determining specialization. We refer to Total Factor Productivity (TFP) which indicates by labor productivity increased rate. Our calculations obtained that TFP due to opened trade barriers (reducing by tariffs) with iceberg transportation cost model are proved consistently with Eaton-Kortum (2002), where production shift to larger countries (European Union and United States) and emerging countries such as Brazil, and China. The distance may lead for the workers mobile in nearby countries approaches that where the improvement occurred. Another issues that we have to delivered in this paper is demand for fossil energy in countries analysis. It seems that Indonesia according to our CGE model is one of the countries whose largest increasing percentage demand for energy. The reducing tariff for biofuel in Indonesia only increase export on biofuel but still depend on fossil fuel energy. This condition is the truth facts that in Indonesia as a case, the biofuel program is only to fulfill trade demand rather than to deal with energy security for self sufficiency. Another stories is different with Brazil, when biofuel as the substitute energy for self sufficiency, biofuel trade could reduce demand for fossil energy as well. For Indonesia and Malaysia, fossil fuel energy still majority consumption for energy in daily live. The strenuous effort to change consumption behavior from fossil energy to another alternative energy, has been challenging for those countries to reduce dependency on fossil fuel. In order to implemet of biofuel policy, this policy has been chalanging issues from policy turn to realization.

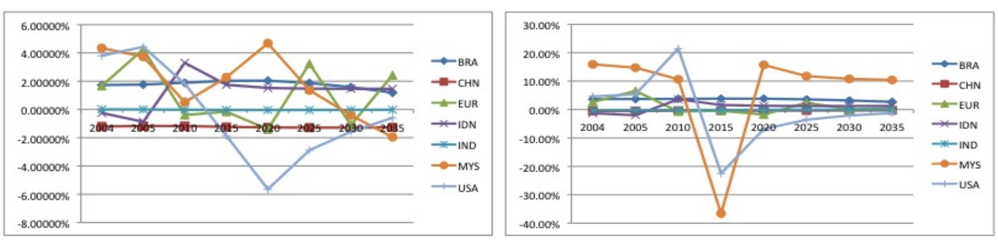

Figure 4: Percentage Change of Total Agrofuel Output - Scenario 1 and 2

Food Security Result. Total output of agrofuel according to our calculation has different impact significantly on Scenario 1 and Scenario 2. In scenario 1, trade liberalization has increased sharply in Indonesia, demand for biofuel has led Indonesia to produce more biofuel product for European Union and India (see Figure 4). Otherwise, for Brazil due to reducing tariff on import, consequently production of biofuel decrease sharply. When we reduces tariff become 97% for biofuel trade, the result contrast than previous result, production increase tremendously for biofuel production in Brazil, China, and India. Production biofuel in Indonesia falling down sharply, otherwise for Brazil produce more agrofuel get more benefit accordingly. In export Brazil and Indonesia are the countries which have advantage rather than other countries for trading in biofuel commodities. In fact, United States (US) has paid cost due to this policy (see Figure 5). US welfare on export fluctuated during period 2004-2035, shown us that US become net import country of biofuel commodities in the future. Although, US has concerned about biofuel policy, fossil fuel policy energy and other renewable energy source still decisive source which more priority to meet demand for energy in the future. Reducing import tariff for Biofuel product has increased price in Agriculture Product and Energy.

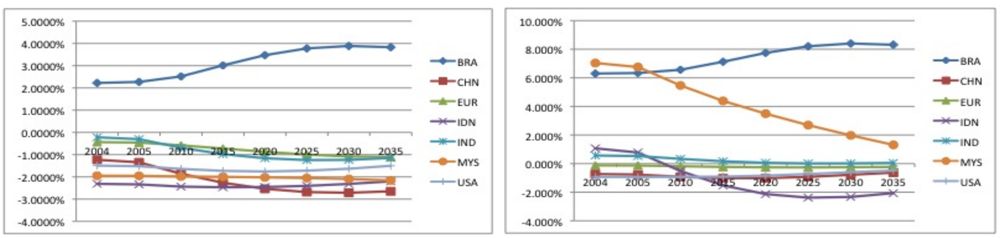

Figure 5: Percentage Change of Agrofuel Export - Scenario 1 and 2

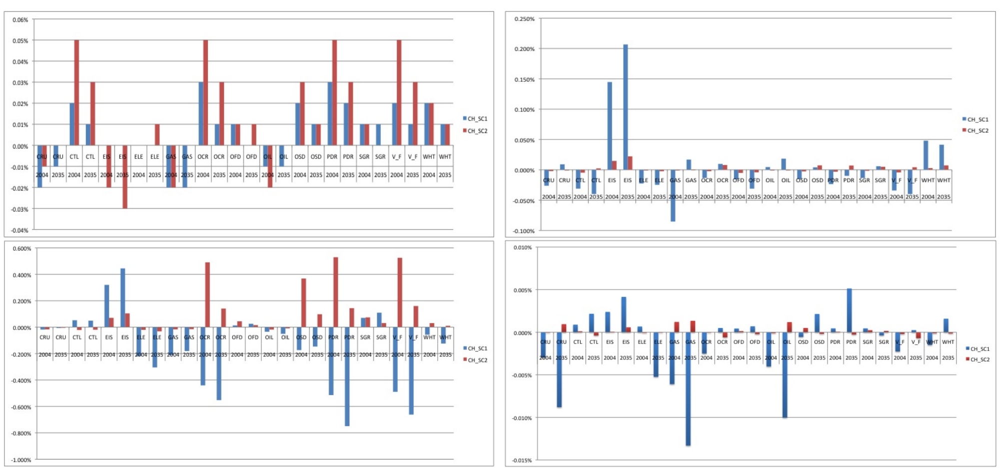

Figure 6: Percentage Change in Agrc. Comm. and Energy Prices 2004-2035 - Scenario 1 and 2

In Indonesia, decreasing import tariff simultaneously increase price in Biodiesel and decrease in agriculture product. Thereby, in Indonesia, trade

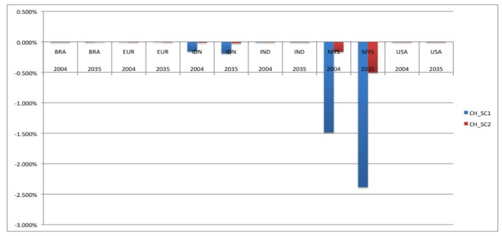

Figure 7: Percentage Change of Agrofuel Export - Scenario 1 and 2

liberalization in Biofuel product is not much affected to other agriculture price (see Figure 6). For Malaysia increasing of reduce import tariff caused increase in agriculture price, and decrease fossil fuels product. Although in first scenario, those scenario has decreased for agriculture commodities price in Malaysia, apart from that decreasing import tariff yields increasing in agriculture product. In European Union area, reducing import tariff somewhat impact on price of agriculture commodities. The total impact which imposed by scenario has decreased PPP particulary for Malaysia and Indonesia (see Figure 7). This surprising result what we did not expected, the trade liberalization in Biofuel decrease real wage totally, we suspect that increasing benefit totally is not reflect as well as wage, the increase in relative price in commodity is not associate with increase in wage, because the increasing of relative price movement in agriculture product bigger than increase in wage. This result show us, that for both countries trade liberalization for biofuel product associated with increasing price for another commodities. As we seen in Figure 7, trade liberalization impact on agriculture product price for Malaysia especially and Indonesia as well.

5. Conclusion

Imposing trade liberalization tends to increase in price of agriculture product and decrease in real wage. Openness of Biofuel product made benefit for exporter countries and cost for importer countries. This phenomenon apparently according to the theories of comparative advantage where the natural abundance countries has benefit and creates potential gains from trade. Our conclusion in term of Food Security regarding those indicators are the trade liberalization may impact somewhat on price and real wage, but in term of supply trade liberalization may increase in welfare export and output accordingly. These result is similar with Kretschmer-Peterson (2009b) and Banse, et.al (2008), Biofuel policy may caused decreasing welfare for importer countries and increase welfare for exporter countries. We have developed CGE model that captures the geographical term in conventional CGE and produce consistency according to the theories. Another issue arose in this paper, that global biofuel policy issues for developing countries much less attracted only to increase gains from trade, but not for self sufficiency in term of energy security. The strenuous effort to changing of fossil fuels consumption to another energy alternative in developing countries is more difficult to be implemented.

List of Equations in The CGE Model

Table .1: Notation in the CGE Model

Sets	i	Sectors and goods
	j	Aliased with i
	r	Regions
	s	Aliased with r
	EG	All energy goods: coal, crude oil, refined oil, gas, and electricity
	FF	Primary fossil fuels: coal, crude oil and gas
	LQ	Liquid fuels: crude oil and gas
Activity variables	Y_{ir}	Production in sector i and region r
	E_{ir}	Aggregate energy input sector i and region r
	M_{ir}	Armington aggregate for demand category of i in region r
	A_{ir}	Armington aggregate for demand category
	C_{ir}	Aggregate households consumption in region r
	E_{ir}	Aggregate households energy consumption in region r
Price variables	P_{ir}	Output price of good i produced in region r for dom. market
	P_{ir}^X	Output price of good i produced in region r for export market
	P_{ir}^E	Price of aggregate of good i produce in region r for export market
	P_{ir}^M	Import price of aggregate of good i imported to region r
	P_{ir}^A	Price Armington of good i in region r
	P_{ir}^C	Price of aggregate hh consumption in region r
	P_{ir}^E	Price of aggregate hh energy energy consumption in region r
	w_r	Wage rate in region r
	v_r	Price of capital services in region r
	E_{Cr}	Rent to natural resources in region r

Table .2: Notation in the CGE Model

Cost shares	θ_r^X	Share of export in sector i in region r
	θ_{ir}	Share of intermediate good j and sector i and region r
	θ_r^{KLE}	Share of KLE aggregate in sector i and region r
	θ_r^E	Share of energy sector i and region r
	$\theta_r^{K,L}$	Share of labor or capital in sector i and region r
	θ_{ir}^T	Share of natural resource in sector i and region r
	θ_{ir}^Q	Share of good i or labor or capital in sector i and region r
	θ_{ir}^{COA}	Share of coal in fossil fuel demand by sector
	β_{jir}	Share of liquid fossil fuel demand sector
	θ_{sir}^M	Share of import good i from region s to region r
	θ_{ir}^A	Share of domestic variety in Armington good i of region r
	θ_{Cr}^E	Share of non energy good in non energy hh cons. in reg. r
	θ_{iCr}^E	Share of fossil fuels in hh energy consumption in region r
Endowment	L_r	Aggregate Labor Endowment
	K_r	Aggregate capital endowment for region r
	Q_r	Endowment of natural resource i for region r
	Λ_r	Endowment of Land
Elasticities	η	Transformation between prod. dom and export
	σ	Elasticity of substitution

Appendix A. Block of Equations

Appendix A.1. Production

Aggregate Income:

$$Y_{irt} = (\alpha_{irt} D_{irt}^{\eta} + \beta_{irt} X_{irt}^{\eta})^{1/\eta} \tag{A.1}$$

Top level fossil fuel production:

$$Y_{nrt} = min\left(\theta_{nrt}\{\alpha_{nr} E_{nrt}^{\rho^{KLET}} + \beta_{nr} KL\Lambda_{nr}^{\rho^{KLET}}\}^{1/\rho^{KLET}}\right) \tag{A.2}$$

Second level of non fossil fuel production:

$$KL\Lambda_{nrt} = \phi_{nrt}\left(\alpha_{nrt} K_{nrt}^{\rho^{KL\Lambda}} + \beta_{nr} L_{nrt}^{\rho^{KL\Lambda}} + \chi_{nrt} \Lambda_{nrt}^{\rho^{KL\Lambda}}\right)^{1/\rho^{KL\Lambda}} \tag{A.3}$$

Third level of non fossil fuel production:

$$E_{nrt}\phi_{nrt}\left(\alpha_{nrt} ELE_{nrt}^{\rho^{E}} + \beta_{nrt} FF_{nrt}^{\rho^{E}}\right)^{1/\rho^{KL\Lambda}} \tag{A.4}$$

Fourth level of non fossil fuel production:

$$FF_{nrt} = \left(\alpha_{frt} COA_{nrt}^{\rho^{COA}} + \beta_{nrt}\{OIL^{\theta_{nr}} \cdot GAS^{1-\theta_{nr}}\}^{\rho^{COA}}\right) \tag{A.5}$$

Fossil fuel production:

$$Y_{frt} = \left(\alpha_{frt} R_{rt} + \beta_{frt}\{min\left[\theta_{frt}^{K} K_{frt} \theta_{frt}^{L} L_{frt} \theta_{frt}^{E} E_{frt} \theta_{frt}^{M} M_{frt}\right]\}^{\rho_{fr}^{f}}\right)^{1/\rho_{fr}^{f}} \tag{A.6}$$

Appendix A.2. Factor Demand

Variable input coefficient for labor:

$$a_{nr}^{L} = \theta_{nr}\phi_{nrt}^{\rho^{KL\Lambda}-1}\hat{\phi}_{nrt}^{\rho^{KLE\Lambda}-1}\left(\hat{\beta}_{nr}\frac{PKL\Lambda_{nr}}{PL_{nr}}\right)^{\sigma^{KL\Lambda}}\left(\hat{\beta}_{nr}\frac{PY_{nr}}{PKL\Lambda_{nr}}\right)^{\sigma^{KLE\Lambda}} \tag{A.7}$$

Variable input coefficient for land:

$$a_{nr}^{T} = \theta_{nr}\phi_{nrt}^{\rho^{KL\Lambda}-1}\hat{\phi}_{nrt}^{\rho^{KLE\Lambda}-1}\left(\hat{\beta}_{nr}\frac{PKL\Lambda_{nr}}{P\Lambda_{nr}}\right)^{\sigma^{KL\Lambda}}\left(\hat{\beta}_{nr}\frac{PY_{nr}}{PKL\Lambda_{nr}}\right)^{\sigma^{KLE\Lambda}} \tag{A.8}$$

Appendix A.3. Households

Consumption:

$$U_r = \left[\alpha_r \left(\sum_{fe} \beta_{fe} C_{fe}^{\rho_F} \right) + \phi_r \left(\prod_{j \notin fe} C_{jr}^{\theta_i} \right)^{\rho^C} \right]^{1/\rho} \tag{A.9}$$

Total Revenue:

$$\begin{aligned} TR_{rt} = \sum_{is} (tm_{isr} \cdot (VTWR_{isrt} + VXMD_{isrt} \cdot (1 + tx_{isrt}) \\ + tx_{isr} \cdot VXMD_{irst}) + \sum_{ij} (ti_{jirt} \cdot VAFM_{jirt}) \\ + \sum_{ij} (ty_{irt} \cdot VOM_{irt}) + \sum_{i} (tc_{irt} \cdot c0_{irt}) \end{aligned} \tag{A.10}$$

Appendix A.4. Foreign Trade

Import:

$$\hat{M}_{irt} = \phi_{irt} \left[\sum_{s} \alpha_{irt} X_{isr}^{\rho^X} \right]^{1/\rho^X} \tag{A.11}$$

Export :

$$X_{irt} = \phi_{irt} \left[\sum_{r} \alpha_{irt} X_{irs}^{\rho^X} \right]^{1/\rho^X} \tag{A.12}$$

Armington:

$$\hat{A}_{irt} = \phi_{irt} \left(\hat{\alpha}_{irt} \hat{D}_{irt}^{\rho^D} + \hat{\beta}_{ir} \hat{M}_{ir}^{\rho^D} \right) \tag{A.13}$$

Appendix A.5. Labor Supply

$$\bar{L}_{jrt} = \sum_{i} \frac{\lambda_{ijr} c_{ir} Q_{ir}}{w_{jr}} \tag{A.14}$$

Appendix A.6. Welfare Index

$$W_{rt} = \frac{Y_{rt}}{e_{rt}} \tag{A.15}$$

Appendix B. Market Clearance Conditions

Appendix B.1. Domestic Market

Domestic market = Domestic Demand

$$Y_{irt}\frac{\partial \pi^{Y}_{irt}}{\partial PD_{irt}} = \sum_{j} A_{jrt}\frac{\partial \pi^{A}_{jr}}{\partial PD_{irt}} \tag{B.1}$$

Appendix B.2. Foreign Trade

Export Supply = Import Demand

$$Y_{irt}\frac{\partial \pi^{Y}_{irt}}{\partial PX_{irt}} = \sum_{s} M_{ist}\frac{\partial \pi^{M}_{ist}}{\partial PX_{irt}} \tag{B.2}$$

Import Supply = Import Demand

$$M_{irt} = A_{irt}\frac{\partial \pi^{A}_{irt}}{\partial PL_{r}} \tag{B.3}$$

Appendix B.3. Factor Endowment

Labor Endowment = Capital Demand

$$\bar{L}_{rt} = \sum_{i} Y_{irt}\frac{\partial \pi^{Y}_{ir}}{\partial PL_{r}} \tag{B.4}$$

Capital Endowment = Capital Demand

$$\bar{K}_{rt} = \sum_{i} Y_{irt}\frac{\partial \pi^{Y}_{ir}}{\partial PK_{r}} \tag{B.5}$$

Land Endowment = Land Demand

$$\bar{\Lambda}_{rt} = \sum_{i} Y_{irt}\frac{\partial \pi^{Y}_{ir}}{\partial P\Lambda_{r}} \tag{B.6}$$

Resource Endowment = Resource Demand

$$\bar{R}_{rt} = \sum_{i} Y_{irt}\frac{\partial \pi^{Y}_{ir}}{\partial PR_{r}} \tag{B.7}$$

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