Impacts of Large Scale Expansion of Biofuels on Global Poverty and Income Distribution

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Abstract

This paper analyzes the impact of expansion in biofuels on the global economy, income distribution and poverty. It utilizes simulation results of two World Bank models: a global computable general equilibrium (CGE) model integrated with biofuels, land-use, and climate change modules, and a global income distribution model that utilizes household survey data of 116 countries. The first model simulates the effects over time of large scale expansion of biofuels on resource allocation, output prices, commodity prices, factor prices, and household income of the different countries and regions in the world. The second model uses these results recursively to calculate the impact on global income distribution and poverty.

The results from the CGE model indicate that large scale expansion of biofuels lead to higher world prices of sugar, corn, oilseeds, wheat, and other grains, which lead to higher food prices. The increase in food inflation is higher in developing countries than in developed countries. The expansion of biofuels results in higher wages of unskilled rural labor relative to wages of the other labor types which are skilled urban, skilled rural, and unskilled urban, especially in developing countries. These positive wage effects on unskilled rural labor trigger movement of unskilled urban labor towards rural and agriculture. This is because production of feedstock in developing countries is relatively intensive in the use of unskilled rural labor.

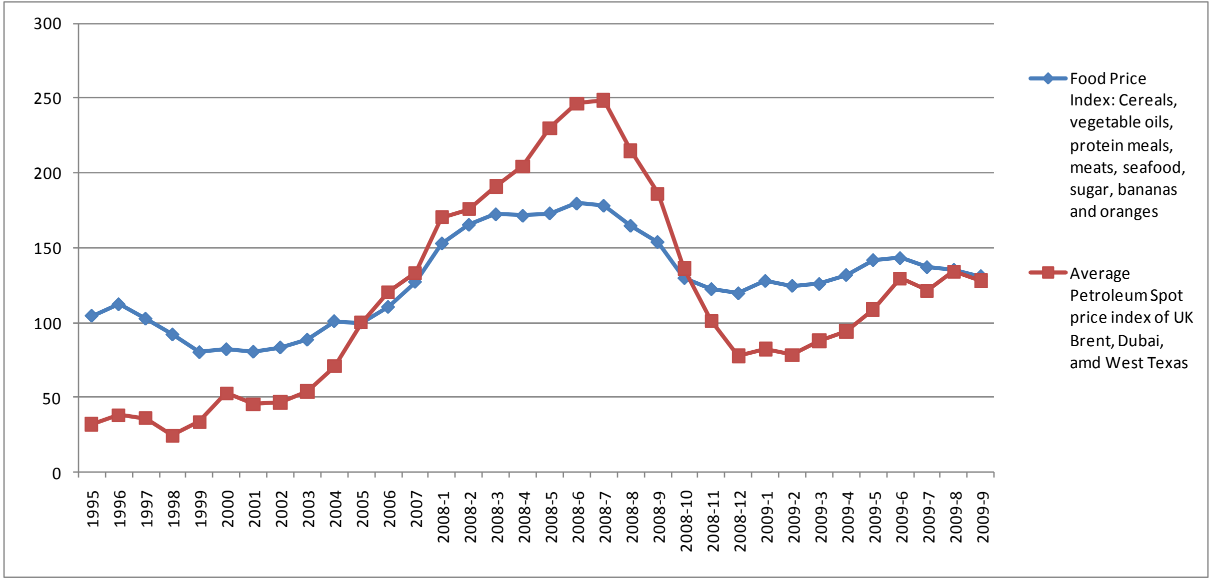
The effects of large scale expansion of biofuels on poverty vary across regions. But overall there is a slight increase in global poverty. The increase largely comes from South Asia (particularly India) and Sub-Saharan Africa. Significant number of countries in Sub-Saharan Africa show higher poverty with large scale expansion of biofuels. However, poverty declines in East Asia and Latin America regions.

Overall, there is a slight increase in the GINI coefficient. There is a slight increase in the GINI coefficient in Sub-Saharan Africa and East Asia. There is a small reduction in the GINI coefficient in the rest of the regions.

Introduction

The index of average prices of oil increased to all-time high at 250 in August 2008 from less than 50 in 1995 (Figure 1). Thus, the search for alternative sources of energy such as biofuels intensified. But recent emphasis on biofuels has triggered worldwide concern because of its effects on global food prices and supply. During this period of high oil prices, the index of average international prices of food rose dramatically from 75 percent in 2000 to 180 August of 2008 (Figure 1). To be sure, there are a host of factors driving each of these price indices, but the concern is based on the fact that biofuel production competes with food production because it utilizes the same raw materials, and therefore limits food supply and puts pressure on food prices to increase. Raw material inputs into first generation production of biofuels consist of sugar, corn, oilseeds, wheat, and other coarse grains.

Figure 1: Food and oil prices



Source: IMF commodity prices (http://www.imf.org/external/np/res/commod/index.asp)

The objective of this paper is to analyze the effects of large scale expansion of biofuels on the global economy, income distribution, and poverty. The analysis uses simulation results generated from two World Bank simulation models: a global computable general equilibrium (CGE) model and a global distribution and poverty model. The first model simulates the effects over time of large scale expansion of biofuels on resource allocation, output prices, commodity prices, factor prices, and household income of different countries and regions in the world. The second model uses these results recursively to calculate the impact on global income distribution and poverty.

There are few studies that analyzed the economic impact of biofuel production using global economic models. Birur, Hertel, Tyner (2008) analyzed the effect of biofuel production on world agricultural markets, and found strong substitution effects towards biofuels when crude oil prices increase. This increases the demand for feedstock, and results in higher acreage towards corn in the United States, oilseeds in the European Union, and sugarcane in Brazil. Furthermore, higher demand for feedstock reduces land area for paddy and wheat production.

In another paper, Hertel, Tyner, and Birur (2008) analyzed the global impact of biofuel mandates in the United States and European Union. They find that if higher biofuel mandates are implemented, the effects on global land-use towards higher acreage for biofuel feedstock production are considerable. Similar conclusion was arrived at in Keeney and Hertel (2008) on biofuel policies in the United States.

de Gorter and Just (2010) applied a partial equilibrium analysis to study the cost and benefit of alternative biofuel policies in the United States. They generated several interesting insights; key of which indicates that ethanol policies in the United States have significant effect on corn prices which increases the inefficiency of farm subsidies, and vice versa. They have also found that trade policies in the United States that discourage international trade such as tariffs and production subsidies reduce the benefits of biofuel mandate.

Runge and Senaur (2007) have indicated that ethanol policies have adverse impact on food prices and therefore on poverty especially in developing countries. Several studies that examined issues on biofuels have argued that ethanol policies have not generally passed the cost-benefit test (Taylor and Van Doren, 2007; and Hahn and Cecot, 2009).

However, using a country level CGE applied to Mozambique, the results of Arndt et al (2008) indicate favorable effects on growth and income distribution of large scale investments in biofuels. The welfare and distributional effects are larger if the production of sugar cane is through contract growers than large plantations because contract growers employ unskilled labor.

Also, contract growers are small farmholders which benefit from higher land rent due to increased sugar cane production. But large scale investment on biofuels reduces traditional exports, and shifts resources such as land and labor towards sugar cane production. Factor prices improve because of competition for factor inputs; but there is higher pressure on food prices and food imports. Furthermore, large scale investment on biofuels increases the inflow of foreign exchange into Mozambique which creates pressure on the real exchange rate to appreciate and which generates negative macroeconomic effects.

The positive farm income effects in Arndt et (2008) were also found in another CGE analysis of expansion biofuels by Hertel (2009) where developing countries with significant agricultural self-employed poverty population benefit from higher factor returns following increased production of biofuels. Gohin (2008) and Banse et al (2008) also found significant increase in factor incomes from higher share of biofuels in the total energy mix in Europe.

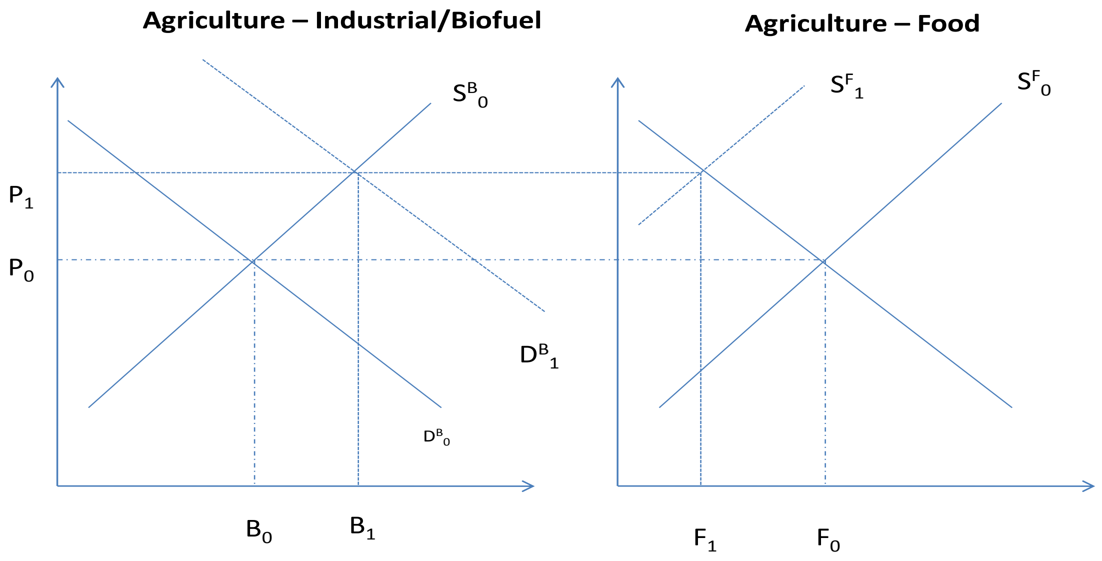
Thus, there is strong evidence that expansion of biofuels divert raw materials from food production to biofuel production, but there are also positive effects on farm income. There are limited studies that analyzed the effects of biofuel policies on food supply, food prices, factor prices, but there are no studies that examine the implications of these policies on global poverty and income distribution. This represents a gap in the literature which this paper attempts to address.

The paper is organized as follows. The second section presents a framework of analysis of how large scale expansion in biofuels affects food supply and prices. Third section discusses the global income distribution and poverty model, focusing on the flow of information from the global CGE model to the data in the household surveys of different countries in the world. The fourth section discusses the definitions of the scenarios examined in the paper. The fifth section discusses the simulation results. The last section gives a summary of results and conclusion.

Framework of Analysis

In this section we present a graphical analysis of demand and supply of agricultural crops to illustrate how an expansion in biofuels can affect food supply and prices. Consider two markets in Figure 2 – market for agricultural crops for industrial use (production of biofuels) and market for agriculture crops for food. The vertical axis is the price of agricultural crops, while the horizon axis the quantity – divided between industrial use and food production.

Figure 2: Agriculture – Food and Industrial Use



Assume the supply of agricultural land is fixed. That is, $L_T = L_B + L_F$, where L_T is fixed total agricultural land available, L_B land used in the production of biofuels, and L_F land used in food production. The market equilibrium price in both markets is P_0, while the equilibrium quantity in the market for biofuels is B_0 and in the food market F_0.

Suppose the demand for biofuels increases (due to higher biofuel target or to higher biofuel production subsidies) from D^B_0 to D^B_1. This leads to higher price at P_1 in the biofuel market. The new equilibrium quantity in biofuels is B_1, which is higher than the previous case, B_0. The impact on the food market is higher price at P_1.

Assume no productivity improvement in both the production of biofuel and food. Since total agricultural land is fixed, the previous food quantity at F_0 cannot be sustained because part of agricultural land devoted to food production shifts to production biofuels. Thus, the supply of food declines, and shifts leftward from $S^F{}_0$ to $S^F{}_1$. The new equilibrium in the food market is F_1, which is lower than F_0. Thus, an expansion in biofuels increases food prices and decreases food supply.

To prevent the negative effects on the food market from a biofuel program, two options may be available: (a) increase the supply of agricultural land (which may have negative implications on climate and negatives effects on agricultural productivity in the long run); or (b) increase agricultural productivity. These options (particularly b) lower agricultural prices (which entail a movement back to P_0) even with higher biofuel demand at $D^B{}_1$. The food supply curve shifts back to $S^F{}_0$ and food production moves back to F_0.

There are factor incomes effects as well. People involved in agricultural production may benefit from higher agricultural prices which lead to improved farm incomes. Returns to land, returns to agricultural capital, and agricultural wages increase with higher agricultural prices. However, the impact on consumer prices (particularly on food prices) may be significant and may eliminate the effects of higher factor returns. Whether the consumer price effects dominate the factor income effects is an empirical issue which will be examined in the present paper. The net effects on households depends upon their net position, i.e., whether they are a net producer or a net consumer of agricultural crops. Furthermore, the reduction of food supply from F_0 to F_1, generates other effects on food supply and prices such as speculative activities because of food security concerns. These are also major issues especially during the 2008 food crisis, but they are not addressed in the present paper.

The Global Income Distribution Dynamics Model

The paper utilizes results generated from two World Bank models. The first model is a CGE model that simulates the effects over time large-scale expansion in biofuels on resource allocation, output prices, commodity prices, factor prices, and household income. The second model is a global income distribution and poverty model which utilizes the results of the CGE in simulating the effects of large-scale expansion of biofuels on income and poverty of the different countries in the world.

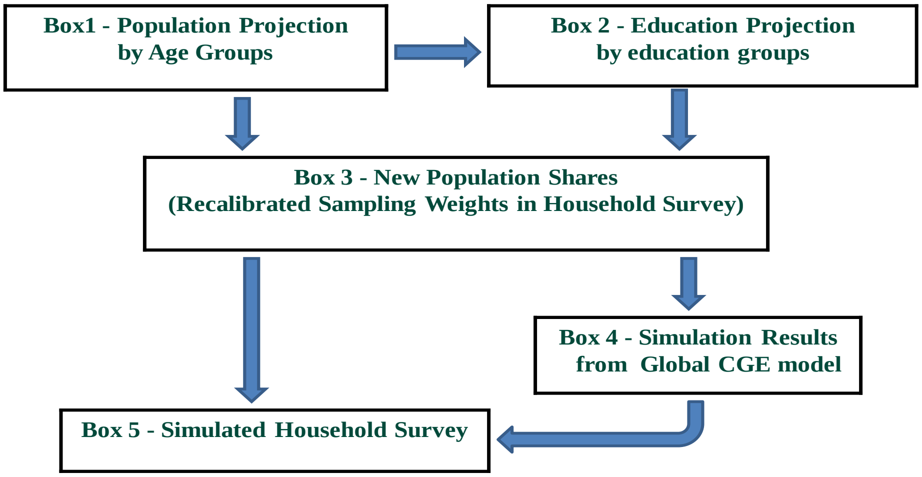
The first model is the Environmental Impact and Sustainability Applied General Equilibrium , or the ENVISAGE model (van der Mensbrugghe, 2009), which is calibrated to the Global Trade Analysis Project (GTAP) Version 7 database with 2004 as the base year. The model incorporates energy volumes and carbon dioxide (CO_2) emission which determine the baseline emissions of CO_2 and other greenhouse gases. The model also incorporates a biofuel module and a land-use module. The biofuel model was incorporated by Mevel (2008), while the specification of the land-use module was based on Beghin (2009) and was incorporated in the ENVISAGE model by Mevel (2008). Appendix 2 gives an overview of the specification of the CGE model with biofuels and land-use modules.

The second model is the Global Income Distribution Dynamics, or the GIDD model (Bussolo, de Hoyos, and Medvedev, 2008), which utilizes the results of the CGE to simulate the effects on global income distribution and poverty. The GIDD model uses household survey data of 116 countries, which represent about 90 percent of the world population. The household survey data, updated to 2005 base year, details the population characteristics of each of the countries such as income, demographic structure and education.

Linking Global CGE and GIDD

The idea in the GIDD model is to project household survey data into the future using three sets of ex-ante macroeconomic information: (a) changes in demographic composition which consist of projection of population by age and by educational attainment; (b) movement of labor between agriculture and non-agriculture; and (c) economic growth. Figure 3 shows how the GIDD model incorporates these three changes to adjust the data in the household surveys in the base year to some year in the future.

Figure 3: Linking Global CGE with GIDD



Source: Bussolo, de Hoyos, and Medvedev (2008)

Box1 contains population projection from the United Nations for nearly 200 countries from 2000 to 2090 in five-year intervals. The population projections are disaggregated into age groups and gender. Box 2 contains the projection of educational attainment based on the population projection in Box 1. The education projection in Box 2 is arrived at using changes in the demographic structure over time. The basic idea in projecting education into the future based on population projection is that the average educational attainment of the population changes through the “pipeline effect” as the population ages. This means that the old and unskilled today will be replaced by the young and more educated skilled individuals as the population age advances. As a result, the overall skill endowment of the population in time t+1 increases as the educational attainment improves.

Information in Box 1 and Box 2 are used in Box 3 to recalibrate the base year weights in the household survey to a new set of weights consistent with the population projection in Box1 and the education attainment projection in Box 2. The basic idea is to search for a new set of sampling weights in the household survey that is consistent with the projected population and education. A detailed discussion of the adjustment process applied is given in Bussolo, de Hoyos and Medvedev (2008).

Let the old sampling weights be

$$(1) \qquad P = \sum_{m=1}^{M} \sum_{n=1}^{N} w_{m,n} = W\mathbf{i}_{\mathrm{n}}\mathbf{i}_{m}^{'}$$

where $\mathbf{i}_{\mathrm{n}}$ and $\mathbf{i}_{\mathrm{m}}$ are identity column vectors, n is the number of observations in the sample, m is a vector of individual-level characteristics targeted in the GIDD process and W are the weights. The sum of all weights, W, is equal to the total population, P. In the present version of the GIDD, the individual-level characteristics are age and education. The row sums yield the totals of the population sub-groups, which are given by

$$(2) \qquad P_m = \sum_{n=1}^{N} w_{m,n} = W\mathbf{i}_{\mathrm{n}}$$

Equation 2 is true for all m. The new sampling weights will incorporate the projected population and education, which is given by

$$(3) \qquad \hat{P}_m = \sum_{n=1}^{N} a_{m,n} w_{m,n} = (A.W)\mathbf{i}_{\mathrm{n}}$$

Equation 3 is true for all m. The matrix $A=[a_{m,n}]$ is a matrix of multipliers which will ensure that the m constraints on the future structure of population $\hat{P}$ are satisfied and $(A.W)$ is the hadamard product. This system has $(m\cdot n - 1)$ variables with m constraints. It is therefore underetermined. In the GIDD model, this problem is addressed through optimization by minimizing the distance between the original matrix W and the final matrix $(A.W)$.[4]

Let the distance function be

$$(4) \qquad D(w_{mn}, a_{mn} w_{mn}) = D(a_{mn})$$

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[4] As an alternative method, the GIDD model addresses this problem by adding equations to make the system exactly identified. The equations added are restrictions that the multipliers must be equal for each subgroup m. However, Bussolo et al (2008) have observed that this process can result in flawed results especially if the sampling units are sufficiently dispersed across the m sub-groups.

Equation 4 is minimized subject to the constraints in equation 3. The first order conditions are:

(5) $$\bar{a}_n = 1 + \sum_{m=1}^{M} \lambda_m w_{m,n}$$

(6) $$\hat{P}_m = \sum_{n=1}^{N} \bar{a}_n w_{m,n}$$

These conditions can be written in matrix form as follows

(7) $$\begin{bmatrix} I & -W' \\ W & 0 \end{bmatrix} = \begin{bmatrix} A \\ \Lambda \end{bmatrix} = \begin{bmatrix} \mathbf{i}_n \\ \hat{P} \end{bmatrix}$$

The solution is

(8) $$\begin{bmatrix} A \\ \Lambda \end{bmatrix} = \begin{bmatrix} 0 & W'(WW')^{-1} \\ -(WW') & (WW')^{-1} \end{bmatrix} \begin{bmatrix} \mathbf{i}_n \\ \hat{P} \end{bmatrix}$$

Equation will yield a simpler expression for Λ

(9) $$\Lambda = \left(WW'\right)^{-1}\left(\hat{P} - W\mathbf{i}_n\right)$$

The matrix that needed to be inverted has a dimension of $(m \cdot n)$. This reduces the dimension of the problem. Once the values for Λ are known, the first order conditions in equation 5 can be used to obtain a solution for the *A* matrix.

The above recalibration process changes the educational endowments of the population in some year in the future, which also changes the labor supply by age and skill groups in the CGE model in Box 4. The CGE incorporates expansion of biofuels policy shocks and simulates the effects into the future on key economic variables such as real per capita GDP and per capita consumption, consumer price index of agriculture and non-agriculture commodities, labor movement between rural and urban and between agriculture and non-agriculture sectors, and changes in wages of various types of labor. These simulated economic effects are used in the GIDD model in Box 5 together with the new set of recalibrated weights in Box 3. The GIDD model uses all this information to calculate the income distribution and poverty effects of large-scale expansion in biofuels in some year in the future.

In projecting the data in the household survey into the future using the simulated results of key economic variables from the CGE and the recalibrated new sampling weights, two other processes are undertaken in the GIDD model. Detailed discussion of the processes is also given in Bussolo, de Hoyos and Medvedev (2008).

The first process involves a movement of labor from the shrinking sector to the expanding sector. Workers that will be moved based on individual characteristics that are inputted into a probit function. For example, the probability of observing individual j working in non-agriculture (*NA*) is

$$(10) \qquad \Pr\left(NA_j = 1\right) = P\left(X_j, Z_j\right)$$

where X_j, and Z_j are vectors of personal and household characteristics of individual j, respectively. The vector of coefficients in equation 10 is $\boldsymbol{\beta}_{\mathbf{p}}$. Given this set of coefficients and the personal and households characteristics, workers are then ordered based on probability score calculated using equation 10. Workers with higher probability to be in non-agriculture are moved out of agriculture up to a point where the predicted share of workers by sector (a macro constraint) is satisfied.

Once the labor movement takes place, the second process involves adjusting income of those who have moved. This income assignment to the "new entrants" in the expanding sector is done through a Mincer equation in agriculture (*A*) and non-agriculture (*NA*).

$$(11) \qquad \ln\left(Y\right)_{j,s} = \mathbf{X}_j \boldsymbol{\beta}_s + \varepsilon_{i,s}$$

where s = (*A*,*NA*). The "new entrants" will carry their personal endowments $\mathbf{X}_j$ and their residual ε_j to sector where they move. However, those who have moved from agriculture to non-agriculture will be paid with prices $\boldsymbol{\beta}_{NA}$. Thus their residuals need to be rescaled in order to incorporate the variances in the distribution of unobservables between agriculture and non-agriculture.

The new income generated in the microsimulation is usually does not match consistently with the income generated in CGE simulation. The GIDD model applies several steps to adjust factor returns by skill type and sector, and average income per capita based on the results of the CGE model.

Let [$y_{s,l}$] be the initial distribution of earnings of labor type l in sector s in the macro data. Define a series of wage gaps ($s+l$ - 1) as follows

$$(12) \qquad g_{s,l} = \frac{y_{s,l}}{y_{1,1}} - 1$$

where $y_{1,1}$ is the average labor earnings of unskilled workers in agriculture. The micro data will have a set of wage premiums [$g'_{s,l}$] which may or may not be consistent with the macro data. In the GIDD model, the counterfactual wage gaps are calculated as follows

$$(13) \qquad \hat{g}'_{s,l} = g'_{s,l} \frac{\hat{g}_{s,l}}{g_{s,s}}$$

If the initial and final wages differ between the macro and micro models, the percentage change in the wage gaps will be consistent across the two models. Note that (13) makes the adjustments in labor income only. Other sources of income have not been adjusted. To adjust them the following process is done

$$(14) \qquad \hat{y}' = y' \frac{\hat{y}}{y}$$

GIDD Dataset

The main sources of data in the GIDD model include: (a) the World Bank World Development Report (WDR) for developing countries, which are drawn largely from the Living Standards and Measurement Study (LSMS) and the African Institute for Sustainability and Peace (ISP)-Poverty monitoring group; (b) the Europe and Central Asia (ECA) databank and the different World Bank sources for Eastern Europe countries, and (c) the Luxembourg Income Studies (LIS) database for most of the developed countries.

There are two versions of the GIDD model. The original version includes data for the year 2000, while the second includes updates for the year 2005. In the original version, nationally representative household surveys of various countries nearest to 2000 were chosen. For household surveys of countries valued not in year 2000, the following adjustments were applied in order to “value” them in 2000. Local consumer price index (CPI) in the country was used to adjust income and consumption to 2000 domestic values. Furthermore, the values in the household surveys were converted to international dollars in year 2000 using the Purchasing Power Parity (PPP) factor obtained from the Penn World Tables. A correction factor was also applied to the population weights to make the population level consistent to year 2000. Finally, all data were converted into vintiles ranking of individuals using household per capita consumption or income. Each vintile contains 5 percent of individuals in a given country.

In the updated GIDD model, the values for 2000 were updated to 2005 using updated population and 2005 PPP factor.

The GIDD database covers all regions in the world. Eastern Europe and Central Asia is 100 percent covered; Latin America 98 percent; South Asia 98 percent; East Asia and Pacific 96 percent; High Income Countries 79 percent; Sub-Saharan African 74 percent; and Middle East and North Africa 70 percent (Ackah, et al, 2008).

The next section defines the various scenarios analyzed in the paper.

Definition of Scenarios

Three scenarios are analyzed over the period 2004-2020:

(1) Business as Usual (*BaU*). This is the baseline scenario which incorporates a number of assumptions. The first set of assumptions is on the world prices of three sources of energy (coal, oil, and natural gas) which are exogenous variables in the model, whose values were derived from the projections calculated outside the model. Table A1 of Appendix 1 shows the price indexes of these three sources of energy used under the *BaU*.

The second set of assumptions pertains to the growth rates of gross domestic product (GDP) of the different countries and regions in the model. The GDP growth rates were based on the growth projections of the World Bank, which are summarized in Table A2 of Appendix 1. To solve the global CGE model with fixed GDP growth rates, another variable in the model which represents the “economywide labor productivity factor” in all countries/regions was made endogenous to replace GDP. The values of this variable are determined in the model.

The third set of assumptions is on the population in each of the countries and regions in the model. Growth rates of population were based on the population growth projection of the United Nations. The population projections are presented in Table A2 of Appendix 1.

The fourth set of assumptions is on the penetration of biofuels in the total fuel mix in each country and region in the model, where total fuel mix is the sum of biofuels, gasoline and diesel. Table 1 shows the biofuel penetration ratio under the *BaU* from 2004 and 2020. In 2004, Brazil has the highest share of 16.86 percent. The rest of the countries and regions have significantly lower biofuel penetration ratio, with the ratios in United States at 1.96 percent and India only at 2.14 percent. The ratios increase gradually over time until 2020. In 2020, Brazil has 41.62 percent ratio. The ratio for the United States is 8.82 percent, Germany 5.97 percent, South Africa 5.59 percent, Russia 5.53 percent, Malaysia 5.10 percent, while the rest of the countries and regions have relatively lower ratios.

Table 1: Biofuel penetration ratio in the total fuel mix, %

				Biofuel penetration ratio under			
	Baseline			Announced targets		Enhanced targets	
	2004	2009	2020	2009	2020	2009	2020
China	1.84	2.08	2.61	2.08	3.65	2.08	7.30
Japan	0.27	0.41	1.01	0.51	1.01	0.81	1.20
Indonesia	1.07	1.77	3.56	1.89	5.00	2.89	10.00
Malaysia	1.02	1.78	5.10	1.81	5.10	3.62	5.10
Thailand	0.68	1.33	2.93	2.00	5.20	4.00	10.40
India	2.14	3.15	5.01	3.15	20.00	5.82	20.00
Canada	0.59	1.06	2.73	2.28	4.10	4.03	8.20
United States	1.96	3.55	8.82	3.55	8.82	5.13	8.82
Argentina	0.90	1.36	3.40	3.18	5.00	5.68	10.00
Brazil	16.86	23.35	41.62	23.35	41.62	23.44	41.62
France	0.88	1.50	4.60	4.25	10.00	7.75	20.00
Germany	1.31	2.21	5.97	4.23	10.00	7.36	20.00
Italy	0.58	0.93	2.58	3.34	10.00	6.21	20.00
Spain	0.47	0.78	2.33	2.34	10.00	4.29	20.00
United Kingdom	0.20	0.34	1.01	2.50	10.00	5.00	20.00
Russia	1.57	2.70	5.53	2.69	5.45	2.68	5.34
South Africa	1.71	3.07	5.59	3.07	5.59	3.26	5.59
Rest European Union and EFTA	0.33	0.54	1.47	3.15	10.00	6.02	20.00
Rest of Latin America and Caribbean	0.49	0.85	2.14	1.07	2.14	2.14	2.96
Australia and New Zealand	0.24	0.40	1.05	0.53	1.23	0.87	2.46
Rest of East Asia and Pacific	0.29	0.44	1.03	0.44	1.49	0.68	2.50
Rest of South Asia	0.40	0.51	0.93	0.49	0.91	0.48	0.87
Rest of Europe and Central Asia	0.46	0.76	1.92	0.76	1.88	0.76	1.84
Middle East and North Africa	0.04	0.06	0.16	0.06	0.15	0.06	0.15
Rest Sub-Saharan Africa	0.79	1.33	3.54	1.32	3.39	1.29	3.30

(2) Announced Biofuel Targets (*AT*). This scenario employs all assumptions in the *BaU*, except for much higher biofuel penetration ratios through 2020 (Table 1). There are notable increases in the ratios for India, Thailand, France, Germany, Italy, Spain, United Kingdom, and in the rest of European Union. The ratios for Brazil, United States, and Malaysia under the *BaU* are retained in the present scenario at 41.62 percent, 8.82 percent and 5.10 percent, respectively.

(3) Enhanced Biofuel Targets (*ET*). This scenario applies a large scale expansion of biofuels through higher biofuel penetration ratios compared to the *BaU* and *AT* scenarios (Table1), except for the ratios for Brazil, United States and Malaysia where are retained at the *BaU* level. The ratios for European countries are increased from 10 percent in *AT* to 20 percent

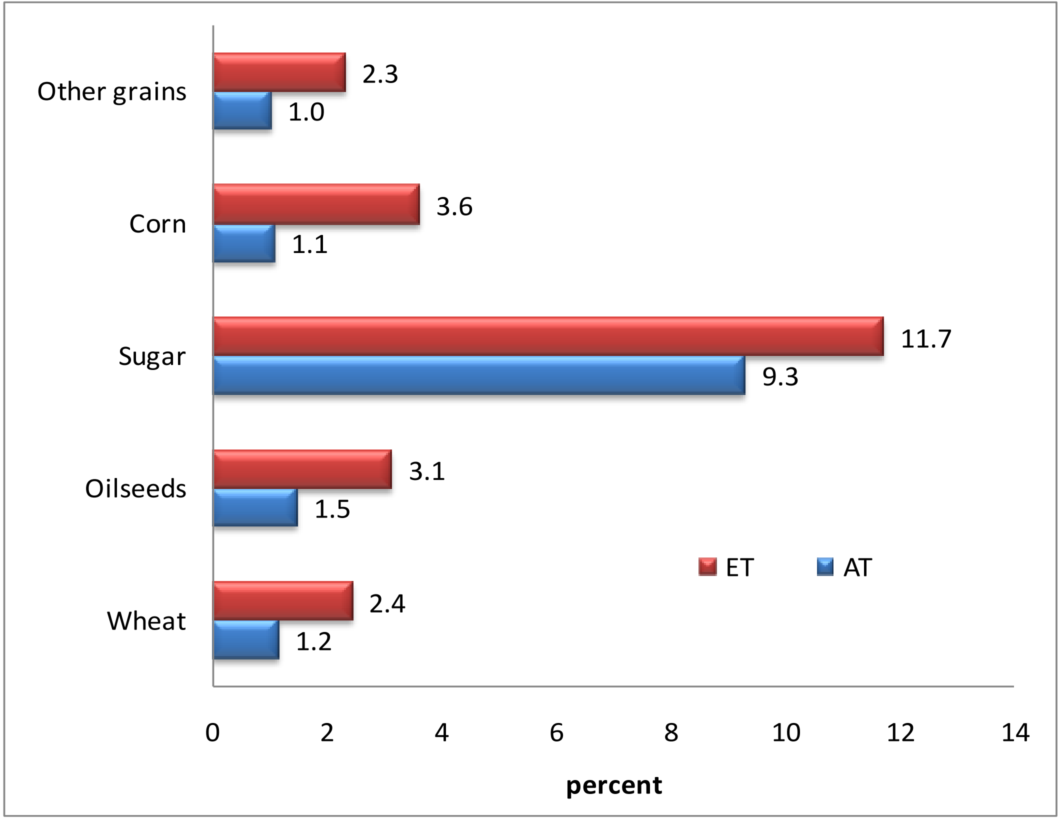
in *ET*, Indonesia from 5 percent in *AT* to 10 percent in *ET*. The ratio for China is increased from 3.65 percent in *AT* to 7.30 percent in *ET*. There are minor changes in the biofuel penetration ratios in the rest of the countries/regions between *AT* and *ET*.

Simulation Results

Selected CGE Results

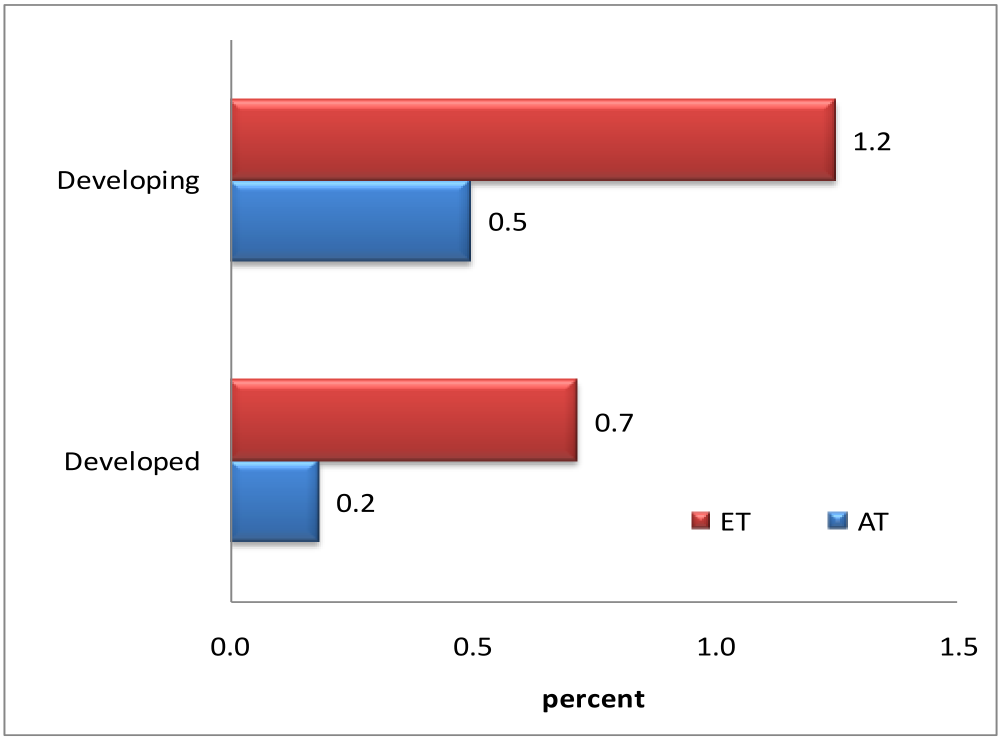
Expansion of biofuels has on world prices of feedstock (Figure 4). Relative to *BaU*, the world price of sugar is higher in 2020 by 11.7 percent in the *ET* scenario and 9.3 percent in *AT*. The world price of corn increases by 3.6 percent in *ET* and 1.1 percent in *AT*. The world price of oilseeds is higher by 4.6 percent in *ET* and 2 percent in *AT*. The world price of wheat increases by 3.1 percent in *ET* and 1.5 percent in *AT*, while world price of wheat is higher by 2.4 percent in *ET* and 1.2 percent in *AT*.

Figure 4: World prices of feedstock in 2020, % change between biofuel expansion and BaU



Higher prices of these crops lead to higher food prices. The impact on the food consumer price index (CPI) is higher in developing countries than in developed countries (Figure 5). For developing countries food CPI increases by 0.5 percent in 2020 in *AT*, but for developed countries the increase is only 0.2 percent[5]. Food CPI increases by 1.2 percent in *ET* in developing countries in 2020, but only by 0.7 percent in developed countries.[6]

Figure 5: Food consumer price index - % change between biofuel expansion and *BaU* in 2020



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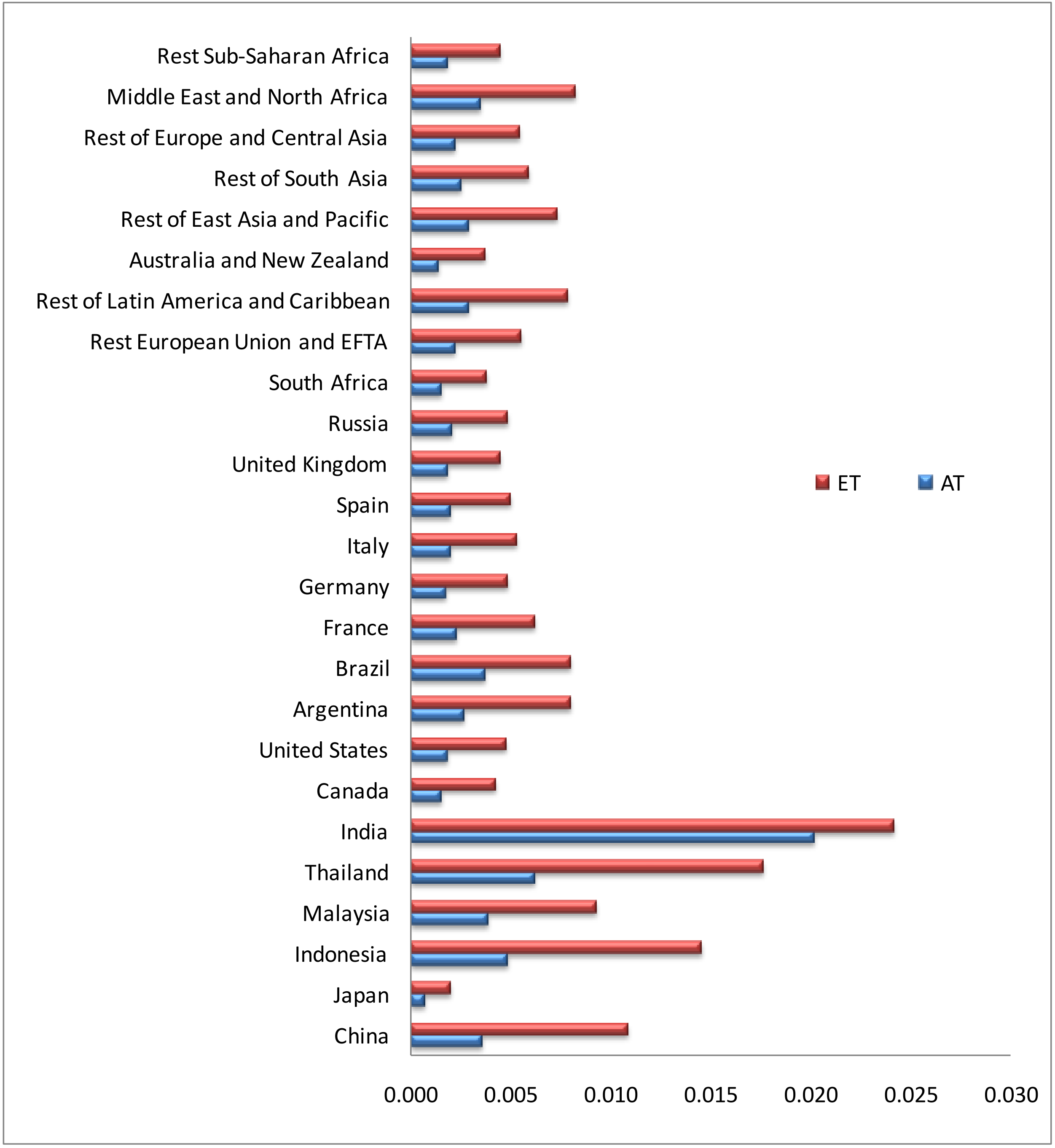
[5] Developed countries in the model include Japan, Canada, United States, France, Germany, Italy, Spain, United Kingdom, Australia and New Zealand, and the rest of European Union and European Free Trade Area, while developing countries in the computation include China, Indonesia, Malaysia, Thailand, India, Argentina, Brazil, Russia, South Africa, rest of Latin America and Caribbean (including rest of North America), rest of East Asia and Pacific (including Korea, Singapore and Taiwan), rest of South Asia, rest of Europe and Central Asia (including Turkey), Middle East and North Africa, and rest of Sub-Sahara Africa.

[6] These price changes are for 2020, but there is gradual increase in food CPI every year after the expansion in biofuels is implemented starting in 2009.

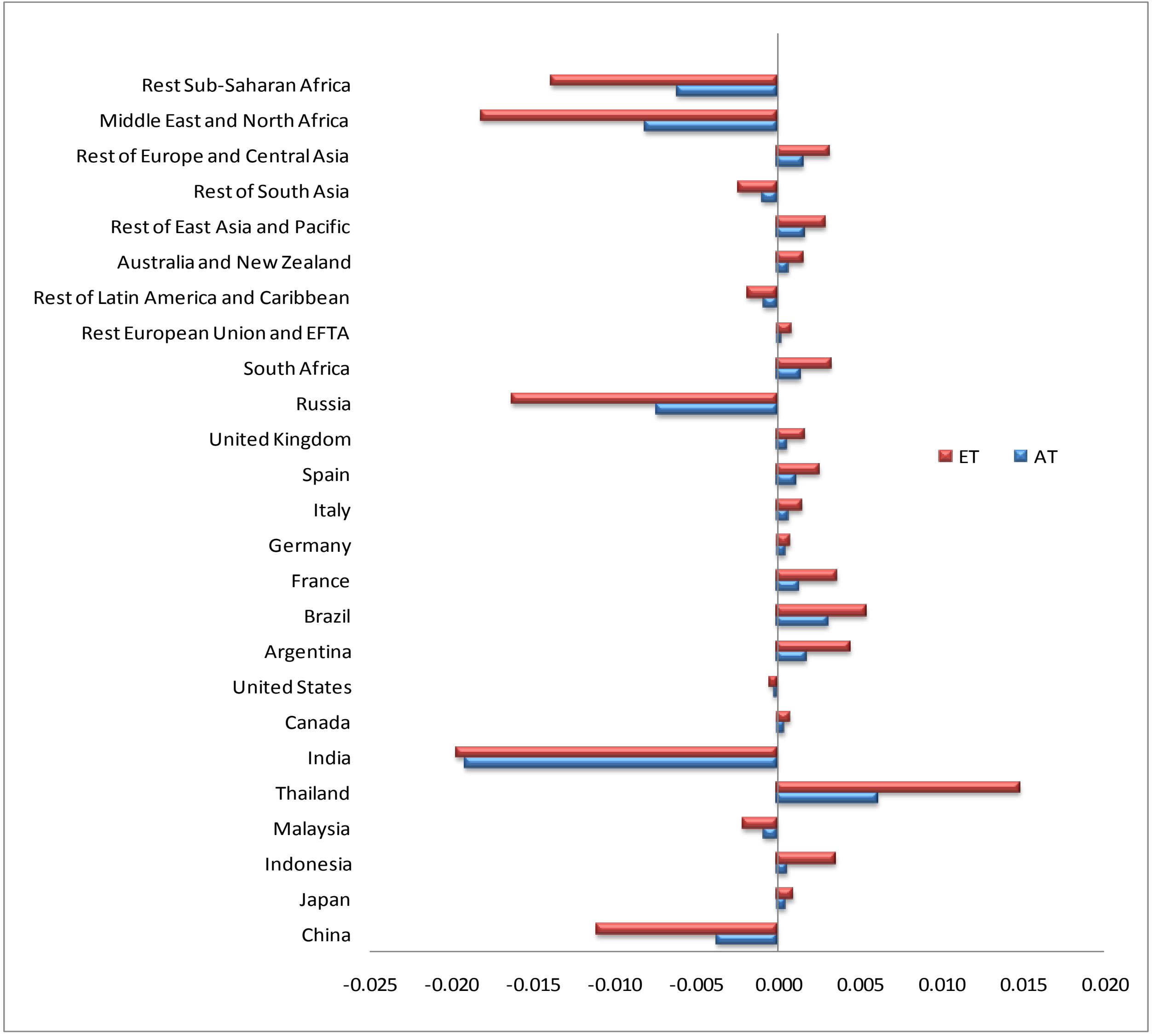
Among the developing countries, East Asian countries have the highest increase in food CPI both in *AT* and *ET* relative to *BaU* (Figure 6). The increase in food CPI in Latin American and African countries is also notable relative to the increase in developed countries.

Figure 6: Country and regional food inflation - biofuel expansion less *BaU* (%)



The effects on real per capita GDP vary considerably across countries and regions (Figure 7). While Thailand shows relatively higher increase in food prices in Figure 6, it is partly offset by the positive increase in real per capita GDP in both scenarios. Similar pattern is observed in Indonesia. But this is not the case for Sub-Saharan Africa region where poverty incidence is highest as we shall see below. In Sub-Saharan Africa there is higher food prices and contraction in real per capita GDP. This is also true for Middle East and North African region, India, and Russia.

Figure 7: Change in real per capita GDP growth - biofuel expansion less *BaU* (%)



Expansion of biofuels leads to larger demand for feedstock and higher demand for factors used heavily in feedstock production. Prices of these factors are expected to increase. In the CGE model, there are four types of labor: skilled urban labor, skilled rural labor, unskilled urban labor, and unskilled rural labor. In presentation of results below, wages of various labor skills are expressed as ratios relative to the wage of unskilled rural labor. The effects on the wage ratios under each scenario are compared to the baseline.

The effects on the wage ratios of the various labor types in *AT* are presented in Figure 8. Except for the United States, wages in all countries and regions decline relative to the wage of unskilled rural labor, which implies higher wage for unskilled rural labor. The decline in wages of various labor skills relative to the wage of unskilled rural labor is generally higher in developing countries than in developed countries. This is because feedstock production in developing countries is relatively intensive in the use of unskilled rural labor. The highest increase in the wage of unskilled rural labor is in India, Middle East and North Africa, Sub-Saharan Africa, Brazil, Argentina, Thailand, Indonesia, and the rest of Latin America. Similar pattern of wage effects is observed in *ET* (Figure 9), but this time there is relatively higher wage change in Middle East and North Africa and Sub-Saharan Africa.

Figure 8: Wage relative to rural unskilled wage, % change between *AT* and *BaU*

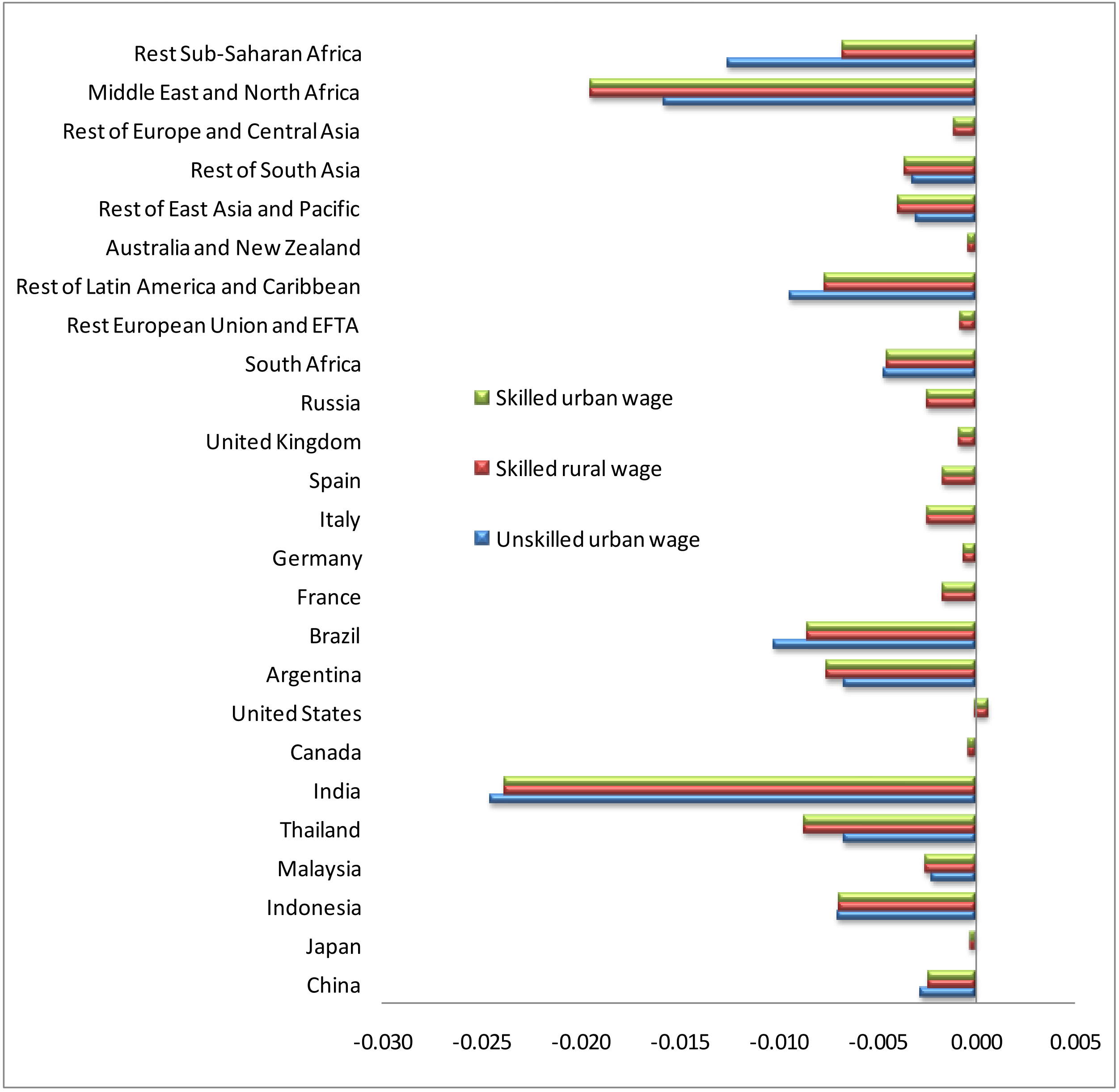
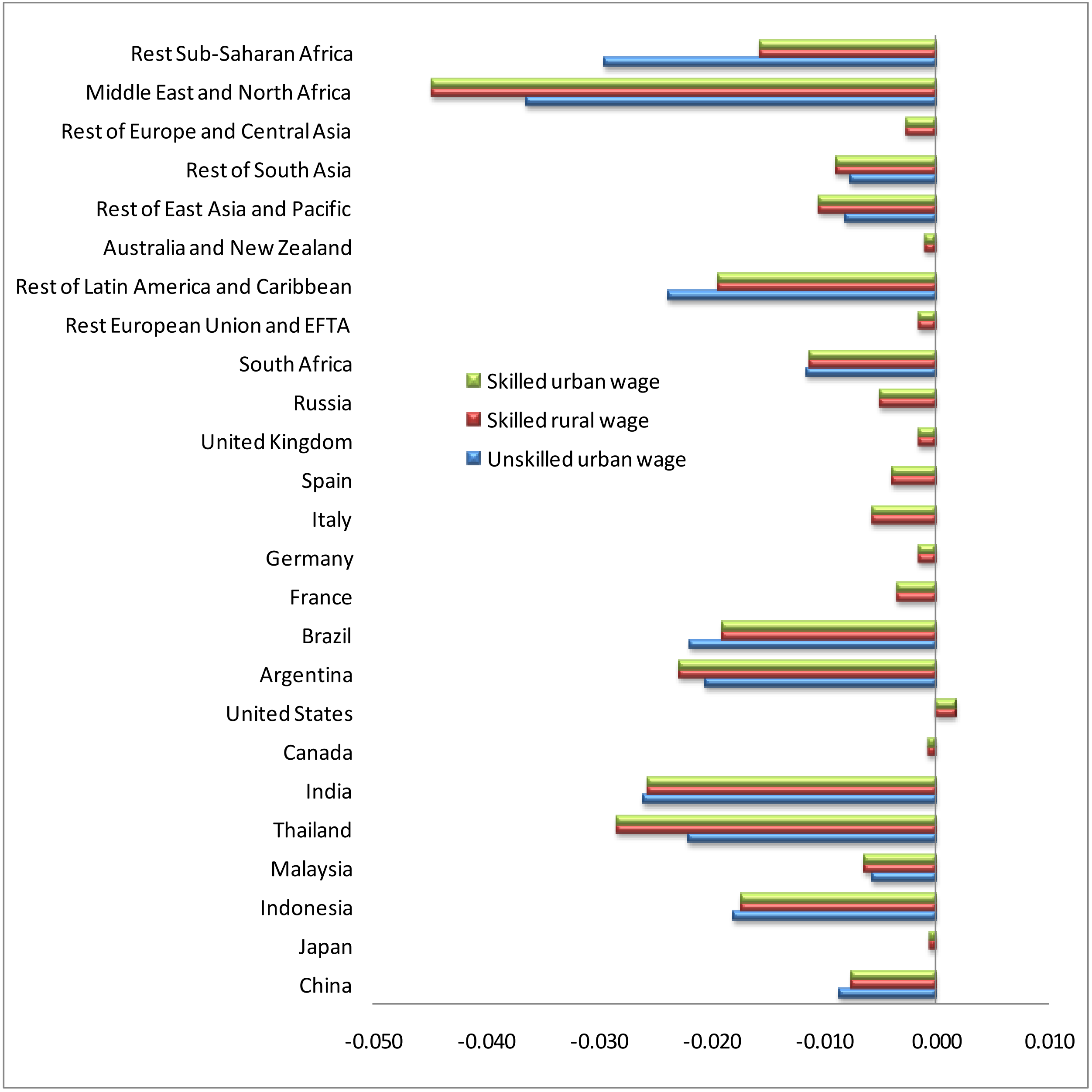


Figure 9: Wage relative to rural unskilled wage, % change between *ET* and *BaU*



Relatively higher wage for unskilled rural labor attracts unskilled urban labor towards rural and agriculture. There are no movement of unskilled labor in developed countries, but there notable shifts in developing countries (Figure 10 and Figure 11). In both scenarios there is a decline in unskilled urban labor relative to the baseline and a corresponding increase in unskilled rural labor in developing countries with expansion in biofuels. This is in response to the higher relative wage for unskilled rural labor. In *AT*, the largest movement of unskilled labor towards agriculture is observed in India and Middle East and North Africa, but there are also labor movement in Brazil, Argentina, Thailand and Indonesia.

Figure 10: Sectoral movement of unskilled labor - % change between *AT* and *BaU*

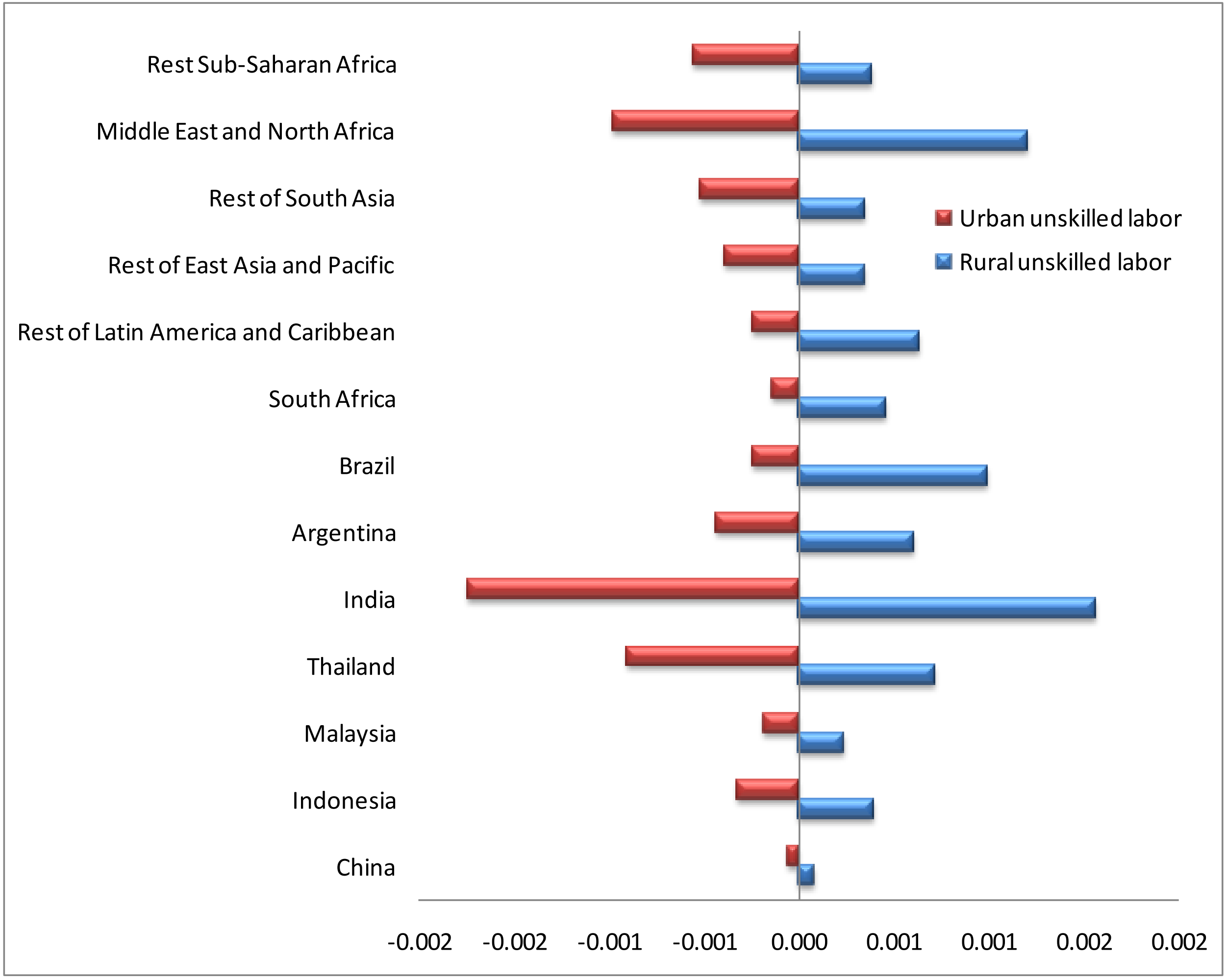
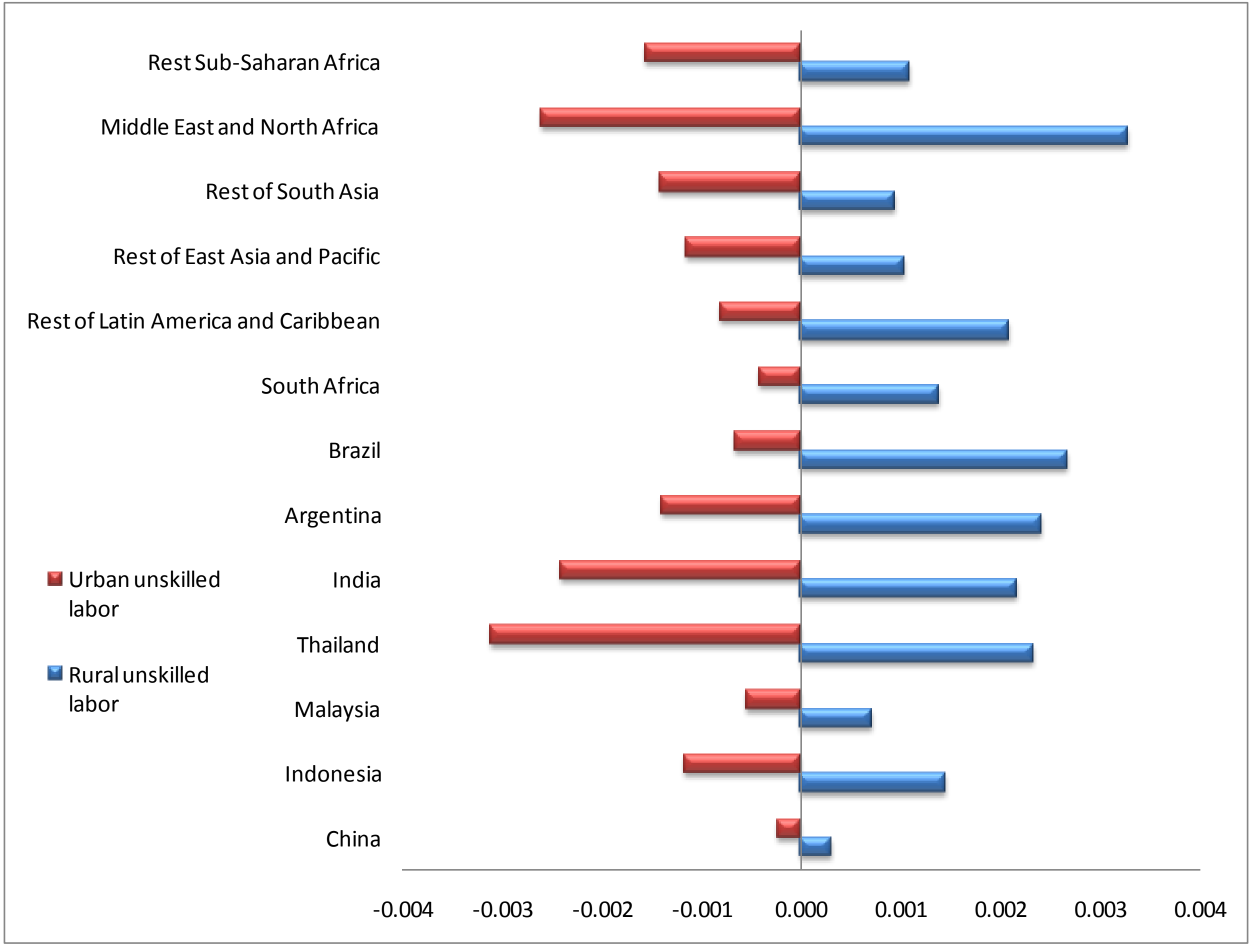


Figure 11: Sectoral movement of unskilled labor - % change between *ET* and *BaU*



Higher wage and demand for unskilled rural labor should lead to favorable labor income effects for agriculture and rural households in developing countries. However, Figure 5 indicates higher increase in food prices in developing as compared to developed countries. Also, Figure 7 shows contraction in real per capita GDP in a few countries/regions, notably India, Middle East and North Africa, Sub-Saharan Africa, Russia and to some extent China. The next section will discuss how these effects will net out and affect income distribution and poverty in developing countries.

Effects on Poverty and Distribution

The CGE results on key economic variables were incorporated into the GIDD model to simulate the distributional and poverty effects of expansion in biofuels. In the poverty analysis, two poverty threshold levels were applied: $1.25 per day and $2.50 per day. In Table 2, we present the GINI coefficient, the poverty headcount, and the poverty incidence of major regions in *BaU* in 2005 and 2020.

The GDP growth projection incorporated in the *BaU* scenario results in falling poverty incidence, poverty headcount and GINI coefficient in all regions between 2005 and 2020. In the $1.25 per day poverty threshold, the global poverty incidence declines from 20.7 percent in 2005 to 8.6 percent in 2020. In the $2.50 per day poverty threshold, the global poverty incidence declines from 49.4 percent in 2005 to 35 percent in 2020. There are large differences across regions. The GINI coefficient also declines from 0.702 in 2005 to 0.673 in 2020, indicating declining income inequality. The GINI coefficients are also significantly different across regions.

Table 2: Poverty and income distribution in *BaU*

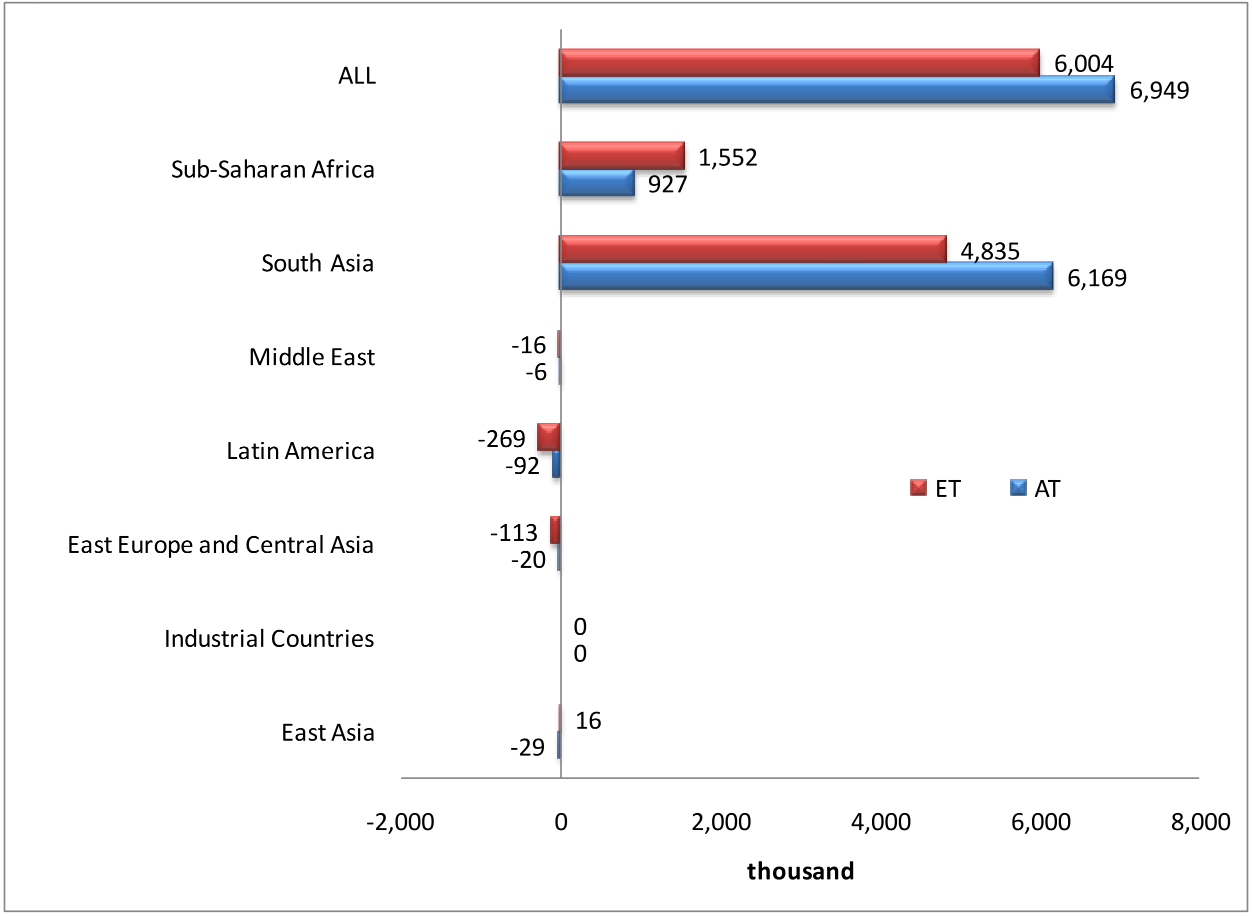
	GINI	Population	Poverty Headcount (million)		Poverty Incidence (%)	
Region	Coefficient	(million)	Poor-1 /a/	Poor-2 /b/	Poor -1	Poor-2
			BaU 2005 /c/			
East Asia	0.4195	1,805	256	895	14.18	49.55
Industrial Countries	0.3905	711	0	3	0.00	0.42
East Europe and Central Asia	0.3933	449	20	76	4.46	16.91
Latin America	0.6077	492	42	110	8.57	22.35
Middle East	0.3985	205	8	57	4.09	27.69
South Asia	0.2923	1,439	583	1,241	40.54	86.27
Sub-Sahara Africa	0.5233	445	239	358	53.57	80.34
ALL	0.7020	5,546	1,148	2,739	20.70	49.38
			BaU 2020			
East Asia	0.3786	2,014	112.2	575.0	5.57	28.55
Industrial Countries	0.4023	744	-	3.0	0.00	0.40
East Europe and Central Asia	0.3661	453	14.8	26.8	3.27	5.92
Latin America	0.5766	591	50.7	139.3	8.58	23.58
Middle East	0.4047	257	0.5	22.9	0.18	8.91
South Asia	0.3184	1,735	204.0	1,114.4	11.76	64.24
Sub-Sahara Africa	0.5489	567	165.1	345.5	29.11	60.89
ALL	0.6517	6,361	547.4	2,226.8	8.60	35.01

/a/ Poor-1 threshold is $1.25 a day
/b/ Poor-2 threshold is $2.50 a day
/c/ Business as usual

The poverty effects of expansion biofuels at the regional level are presented in Figure 12 for the $1.25 per day poverty threshold and in Figure 13 for the $2.50 per day. The country level poverty results are presented in Table 3.

The poverty results are mixed across regions and countries. There is an increase in global poverty headcount both in *AT* and *ET* relative to the baseline. With the $1.25 per day poverty threshold the increase in global poverty headcount is 6 million in *AT* and 6.9 million in *ET*. The increase largely comes from South Asia (6.1 million in *AT* and 4.8 million in *ET*) and Sub-Saharan Africa (927 thousand in *AT* and 1.6 million in *ET*).

Figure 12: Regional poverty effects, biofuel expansion less *BaU* in 2020 ($1.25/day)



The increase in global poverty headcount is slightly higher in the \$2.50 a day poverty threshold. In *AT* the increase is 8.4 million, and in *ET* the increase is 8.1 million. The increase in poverty largely comes from South Asia (8.2 million in *AT* and 8.6 million in *ET*) and Sub-Saharan Africa (756 million in *AT* and 1.3 million in *ET*).

Figure 13: Regional poverty effects, biofuel expansion less *BaU* in 2020 (\$2.50/day)

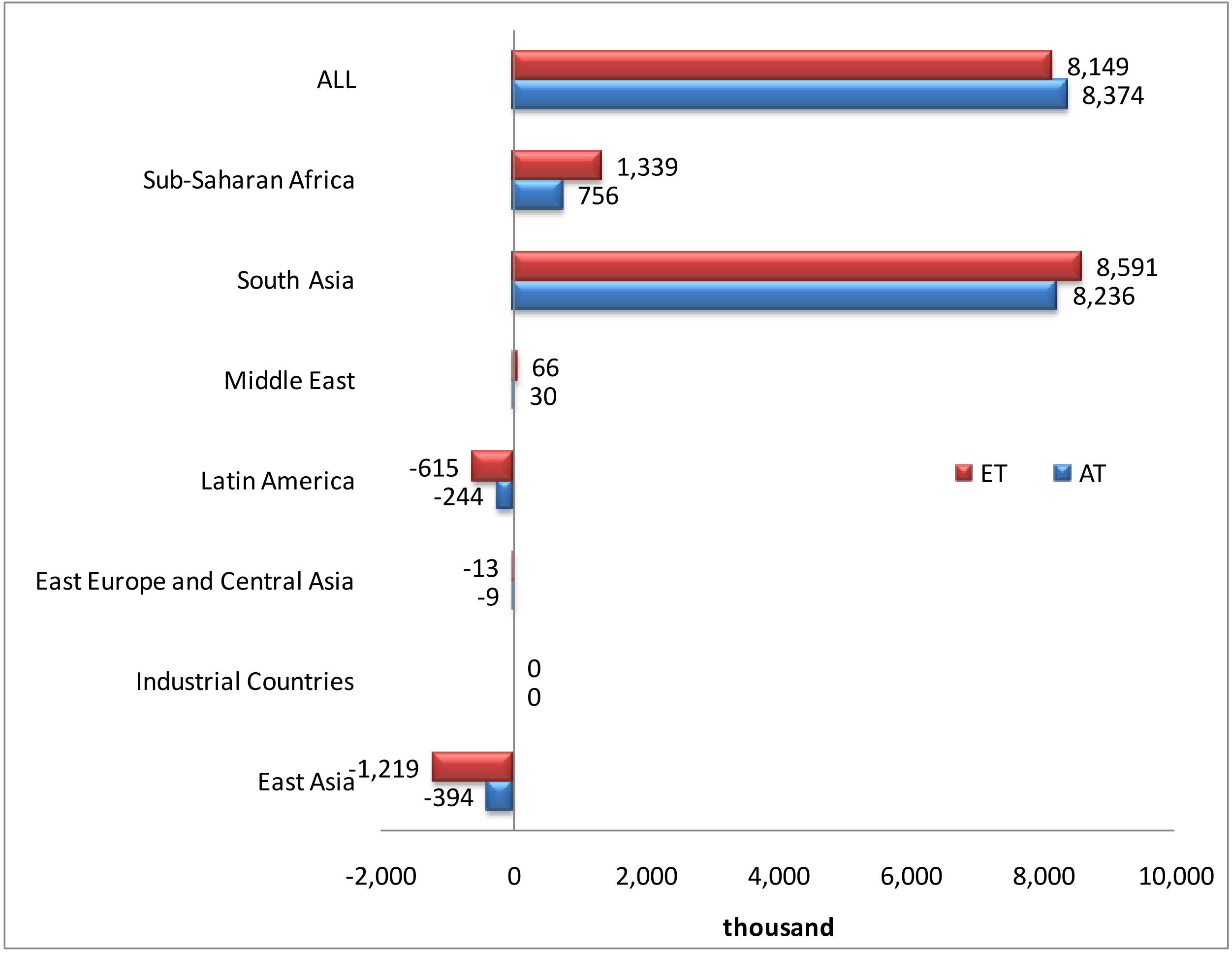


Table 3 presents the poverty results at the country level. Higher poverty is observed in a number of countries in the Sub-Saharan Africa region, especially in Nigeria and Tanzania. But poverty declines in South Africa. Similar poverty effects are observed in *ET*.

The increase in poverty in both *AT* and *ET* largely comes from South Asia. Within the region, the increase in poverty comes from India. There is a slight increase in poverty in Pakistan and Bangladesh.

There is lower poverty in Latin America in both *AT* and *ET*. The effect largely comes from the reduction in poverty in Brazil. There is also lower poverty in East Asia. The reduction in poverty in the region comes from Indonesia, Thailand, and Vietnam. Similarly, there is also lower poverty in East European and Central Asia. In the Middle East, the poverty effects mainly come from Yemen. There is reduction in poverty using the $1.25 per day threshold but there slight increase using $2.50 per day poverty line.

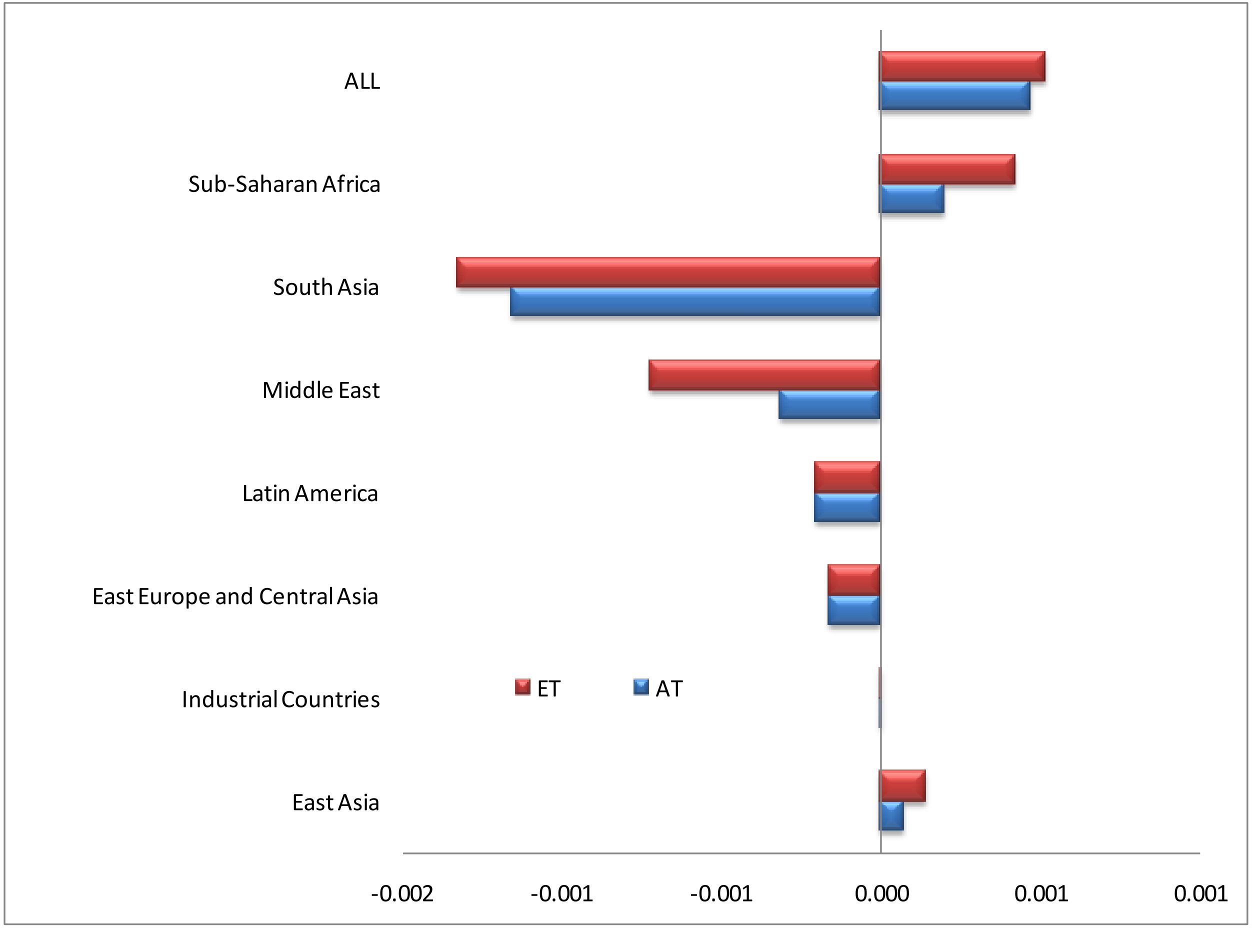
Table 3: Country level poverty effects, biofuel expansion less *BaU* (thousand)

	AT/a/		ET /b/			AT		ET	
	Poor-1 /c/	Poor-2 /d/	Poor-1	Poor-2		Poor-1	Poor-2	Poor-1	Poor-2
Sub-Sahara Africa	927	756	1,552	1,339	East Asia	-29	-394	16	-1,219
Comoros	0	0	0	0	China	0	0	0	0
Lesotho	0	0	0	0	Mongolia	0	0	0	0
Malawi	0	0	0	0	Malaysia	0	0	0	0
Niger	0	0	0	0	Papua New Guinea	0	0	0	0
Rwanda	0	0	0	0	Indonesia	-13	-229	34	-888
Sierra Leone	0	0	0	0	Cambodia	-16	-3	-23	-5
Zambia	0	0	0	0	Philippines	0	-33	0	-75
Burundi	11	15	22	28	Thailand	0	-24	-6	-66
Benin	7	36	29	58	Vietnam	0	-106	11	-185
Burkina Faso	0	19	35	41					
Côte d'Ivoire	2	27	10	56	Latin America	-92	-244	-269	-615
Cameroon	19	51	15	87	Bolivia	-8	4	-16	3
Ghana	15	45	43	125	Brazil	-53	-154	-135	-348
Guinea	40	19	59	14	Chile	-2	-5	-2	-7
Kenya	0	13	0	55	Colombia	-10	-10	-3	-12
Madagascar	53	32	65	70	Costa Rica	0	-2	0	-6
Mali	45	21	68	67	Dominican Republic	0	0	0	0
Mauritania	2	3	4	5	Ecuador	-1	0	-7	0
Nigeria	545	435	780	613	Guatemala	2	0	-38	-8
Senegal	12	24	13	71	Guyana	0	0	0	0
Tanzania	167	73	390	150	Honduras	-3	-6	-12	-7
Uganda	13	2	27	4	Haiti	-10	1	-23	23
South Africa	-4	-58	-7	-104	Jamaica	0	-2	0	-3
					Mexico	0	0	0	0
East Europe and Central Asia	-20	-9	-115	-13	Nicaragua	0	-1	-2	1
Bosnia & Herzegovina	0	0	0	0	Panama	-7	0	-18	-1
Czech Republic	0	0	0	0	Peru	3	-23	-2	-46
Slovak Republic	0	0	0	0	Paraguay	-2	-8	-12	-11
Turkmenistan	0	0	0	0	El Salvador	1	-77	4	-227
Albania	0	0	0	0	Venezuela, Rep. Bol.	0	37	-2	34
Armenia	0	-1	0	-3					
Azerbaijan	0	0	0	-3	Middle East	-6	30	-16	66
Bulgaria	0	0	0	0	Egypt	0	0	0	0
Estonia	0	0	0	0	Iran, I.R. of	0	0	0	0
Georgia	0	-1	0	-1	Tunisia	0	0	0	0
Hungary	-18	0	-76	3	Jordan	0	-1	0	3
Kazakhstan	-1	0	-6	0	Morocco	0	3	0	-4
Kyrgyz Republic	0	-3	0	-3	Yemen, Republic of	-6	28	-16	68
Lithuania	-1	-1	-24	-1					
Moldova	0	-1	0	-2	South Asia	6,169	8,236	4,835	8,591
Macedonia, FYR	0	0	0	0	Bangladesh	85	13	83	96
Poland	0	0	0	0	India	6,051	8,101	4,714	8,255
Romania	0	-2	-1	-4	Sri Lanka	0	-1	3	-8
Russia	0	0	-7	0	Nepal	9	10	8	12
Tajikistan	0	-1	0	-1	Pakistan	24	113	28	235
Turkey	0	0	0	0					
Ukraine	0	0	0	0					
Uzbekistan	0	0	0	2					

/a/ Announced biofuel targets
/b/ Enhanced biofuel targets
/c/ Poor-1 threshold is $1.25 a day
/d/ Poor-2 threshold is $2.50 a day

Figure 14 shows the effects of the expansion in biofuels on income distribution. Note that the results shown are the difference in the GINI coefficient in 2020 between the biofuel scenarios (*AT* and *ET*) and BaU. The change in the GINI coefficient is small across major regions. But overall, there is a slight increase in the GINI coefficient. The GINI coefficient in Sub-Saharan Africa and East Asian region increases, while the rest of the regions have slightly lower GINI.

Figure 14: Change in the GINI coefficient, biofuel expansion less *BaU* in 2020



Conclusion

Biofuels are one of the viable alternative sources of energy. There are increased activities in biofuel production in selected countries. Brazil has made significant headway in sugar ethanol production. The United States has made significant progress in corn ethanol production. Several countries in Europe have stepped up their activities in biodiesel production and have attained respectable level of production of biodiesel.

Recent results in the literature indicate strong substitution effect towards biofuels when crude oil prices increase. Thus, several countries have intensified their production of biofuels in response to the spike in oil prices in 2008. They have also designed long term programs that increase production and use of biofuels. However, given the present technology in the first generation biofuel production which competes heavily for raw materials used in food production, higher production biofuels puts pressure on food supply and on food prices. This has poverty implications, especially for households that are net food buyers.

This paper analyzes the distributional and poverty effects of large scale expansion in biofuels. The paper utilizes simulation results of two World Bank models: a global computable general equilibrium model and a global income distribution and poverty model.

The results from the general equilibrium model indicate that large scale expansion of biofuels leads to higher world prices of sugar, corn, oilseeds, wheat, and other grains, which translate to higher food prices. The increase in food inflation is higher in developing countries than in developed countries.

The impact on real per capita GDP is mixed. Real per capita GDP improves in Thailand, Brazil, Argentina, Indonesia, and some developed countries. But there is notable decline in real per capita GDP in India, Sub-Saharan Africa, Middle East and North African regions, Russia, and China.

Expansion of biofuels leads to higher wages of unskilled rural labor relative to wages of the other labor types which are skilled urban, skilled rural, and unskilled urban. This is true in developing countries. There is small change in the relative wage of unskilled rural labor in developed countries.

These positive wage effects on unskilled rural labor lead to movement of unskilled urban labor towards rural and agriculture. This is because production of feedstock in developing countries is relatively intensive in the use of unskilled rural labor.

Large scale expansion of biofuels leads to a slight increase in poverty. The increase largely comes from South Asia (India) and Sub-Saharan Africa. Significant number of countries in Sub-Saharan Africa shows higher poverty with large scale expansion of biofuels.

The effects on income inequality are very small, but overall, there is a slight increase in the GINI coefficient. There is also a slight increase in the GINI coefficient in Sub-Saharan Africa and East Asian. In the rest of the regions, the GINI coefficient declines.

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Appendices

Appendix 1: Assumptions in Business as Usual

Table A1: World price index of energy

Year/period	World price of coal	World price of oil	World price of natural gas
2004	100.0	100.0	100.0
2005	101.0	104.9	105.4
2006	102.1	110.0	111.1
2007	103.1	115.4	117.0
2008	104.2	121.0	123.3
2009	105.2	126.9	130.0
2010	106.3	133.1	137.0
2011	107.4	139.6	144.4
2012	108.5	146.4	152.1
2013	109.6	153.6	160.3
2014	110.8	161.1	168.9
2015	111.9	168.9	178.0
2020	114.6	168.9	178.4

In 2004-2015 world prices of these commodities are exogenous, but after 2015 they are endogenous

Table A2: Assumptions on GDP and population growth

	GDP growth assumptions, %			Population (million), Growth (%)		
Countries/Regions	2005	2030	Ave. 2005-2030	2004	2030	Growth /a/
China	10.1	7.2	8.6	1306	1483	0.49
Japan	1.9	0.7	1.3	127	117	-0.33
Indonesia	5.7	4.2	5.1	218	281	0.99
Malaysia	5.0	4.0	4.9	25	35	1.26
Thailand	4.5	3.2	3.9	62	70	0.43
India	9.2	6.6	7.6	1079	1409	1.03
Canada	3.1	1.1	1.9	32	34	0.28
United States	3.1	1.3	2.0	292	344	0.63
Argentina	9.2	4.1	5.3	39	48	0.83
Brazil	2.9	2.2	3.1	179	226	0.91
France	1.7	1.0	1.5	60	63	0.22
Germany	0.9	1.2	1.6	83	76	-0.32
Italy	0.2	0.7	1.0	58	51	-0.45
Spain	3.6	2.3	2.7	41	40	-0.11
United Kingdom	1.8	1.6	2.1	59	60	0.02
Russia	6.4	5.0	5.7	143	124	-0.53
South Africa	5.0	4.6	4.7	45	51	0.50
Rest European Union and EFTA /c/	2.9	2.1	2.7	197	191	-0.12
Rest of Latin America and Caribbean	4.5	3.0	3.8	329	448	1.20
Australia and New Zealand	2.8	1.9	2.6	24	28	0.56
Rest of East Asia and Pacific	5.0	5.9	6.5	344	438	0.93
Rest of South Asia	6.7	4.5	5.5	368	554	1.59
Rest of Europe and Central Asia	7.3	5.7	6.1	232	263	0.48
Middle East and North Africa	5.2	3.2	4.1	330	484	1.48
Rest Sub-Saharan Africa	6.2	5.6	6.0	672	1074	1.82
/a/ Geometric growth rate						
/b/ Applied in simulation						
/c/ EFTA -European Free Trade Area						

Appendix 2: The Modified Global CGE Model

The ENVISAGE model incorporates a detailed specification of energy demand in each country, CO2 emissions that are specific to fuel and demand, a simple "climate module that links to greenhouse gas emissions to atmospheric concentrations combined with a carbon cycle that leads to radiative forcing and temperature changes" (van der Mensbrugghe, 2009, p. 1), and flexible system that accommodates various combinations of regulatory policy instruments such as carbon tax, emission caps, and tradable permits.

A detailed discussion of the mathematical specification of the ENVISAGE model is presented in van der Mensbrugghe (2009). The model allows imperfect transformation of output and supply across markets of destination: exports and domestic markets. The transformation is through a two-level nested constant elasticity of transformation (CET) structure. At the first level, output is allocated between domestic sales and aggregate exports. At the second level, aggregate exports are allocated across foreign markets. The specification of the model is flexible because the degree of transformation is determined by the value of the elasticity of transformation at each level. In the ENVISAGE model an infinite transformation is imposed at each of the two nests, which implies that firms treat domestic markets and foreign markets indifferently. Thus, the CET first order conditions are replaced by the law of one price, i.e., export and domestic prices are equal.

The model assumes product differentiation by region of origin through the Armington assumption. This assumption is embedded in the model through a two-level nested constant elasticity of substitution (CES) structure. At the first level the aggregate armington demand is allocated between goods produced domestically and aggregate imports. At the second level, aggregate import is further disaggregated across trading partners. The degree of product differentiation depends upon the magnitude of the substitution elasticity at each level.

At the equilibrium, a vector of equilibrium domestic price equates domestic sales and domestic demand. Similarly, a vector of equilibrium trade price equates bilateral export supply and bilateral import demand.

The allocation of national income is across the following major expenditure items: public expenditures, private expenditures, and investment expenditures. Of the three the largest is private expenditures, which involves household expenditures.

There is one representative household in each region/country. Incomes generated from production are assumed to accrue to this single household. Disposable income of households is allocated between expenditures on goods and services, and savings. Private expenditures of goods and services are defined over consumer goods and are derived as the first order conditions of utility maximization, where the utility function is specified as constant difference in elasticities (CDE). In the model, consumer demand defined over consumer goods is decomposed into producer goods using a CES-based transition matrix. In other words, each consumer good is composed of one or more producer goods. In case there is more than one producer good, the various producer goods are combined using a CES aggregator. Furthermore, each consumer good has its own energy bundle, with different demand shares across energy. Public and investment expenditures are non-energy sectoral armington demand.

The demand for energy is critical in the model. It appears in the consumer side as well as in the production side. We shall elaborate the details of the demand for energy after discussing how it is being affected in the production sector.

Production in each sector is modeled using nested CES functions. There are two derived demands for two commodity bundles: the aggregate intermediate demand and the aggregate value added. The aggregate intermediate demand excludes energy demand. The bundle of value added includes the demand for labor, land, other sector specific factors and the demand for capital and energy combined. The aggregate capital and energy demand is further decomposed into the demand for capital and the demand for energy. There are two capital vintages in the model: old and new. New capital is capital equipment installed at the beginning of the period, while old capital is capital equipment of more than a year age since installation. It is assumed that old capital has lower substitution elasticities than new capital. Countries with higher savings rates have higher share of new capital. Furthermore, new capital is perfectly mobile across production sectors while old capital has low sectoral mobility and is released using an upward sloping supply curve. The total non-energy intermediate demand is decomposed into intermediate demand for non-fuel inputs using armington specification.

Thus, each agent in the economy has a specified demand for aggregate energy bundle. In the model this aggregate energy demand is decomposed into various energy sources, whose structure of decomposition is through different CES nesting levels

At the top level, energy demand is decomposed between electric bundle and non-electric bundle. The electric bundle is decomposed into conventional sources and other alternative technologies.

The closure rules used in the model include: (a) savings of households are endogenous and are affected by demographic factors through a saving function; (b) government revenues are endogenous but government expenditures are a fixed share of nominal gross domestic product; (c) government balance is fixed through a uniform shift in the household direct tax; (d) investment is savings driven; and (e) current account is exogenous, thus foreign savings is fixed. Changes in foreign trade are balanced through changes in the real exchange rate.

There are three factors that drive the dynamics of the model: (a) exogenous growth in population and labor (based on the population projections of the United Nations); (b) capital accumulation (based on capital stock at previous period, investment in the current period and capital depreciation); (c) factor productivity/efficiency parameters which are spread almost throughout the model.

The climate change module in the ENVISAGE model involves a sequence of steps. In the first step, total emissions are derived. For each unit consumption of a commodity in each of the activities (consumption and production), there is a fixed coefficient that determines the level of emission. Total emission is derived as the sum total of all emission by country. In the second step these emissions directly add to the atmosphere, which interact with the ocean, creating a dynamic process that would continue even in the absence of emissions. These set of effects will have an impact on how much energy from the sun is reflected back to space. The third set links all these effects to temperature. All these sequential relationships that determine climate change are established in the model through a set of equations.

Biofuel Extension

Mevel (2008) provides a detailed discussion of the modifications introduced into the global CGE model, including the method of incorporating biofuel data into the GTAP version 7 biofuel. In the model, instead of a simple non-electric bundle nest, the modification introduces a multi-level CES nesting of various sources of non-electric energy.

The aggregate non-electric bundle was disaggregated into three separate bundles: coal; gas; and oil and biofuel combined. The coal bundle and the gas bundle were disaggregated into various sources depending on the level of technology: conventional technologies and alternative technologies.

The major modification introduced into the ENVISAGE model is the elaboration of the sources of oil and biofuels. The oil and biofuel bundle was disaggregated into two sources: (a) bundle of gasoline, diesel, biofuel; and (b) other oil. In the next level, bundle (a) was further disaggregated into (i) bundle of gasoline and diesel; and (ii) biofuel. Thus, in the specification there is a separate demand function for biofuel and a demand function for fossil-based fuel, gasoline and diesel.

Land-Use Extension

The other major extension introduced into the ENVISAGE model was the specification of land supply. This is critical because biofuel production rely use agricultural crops as raw materials. Biofuel production therefore has direct implication on land use. The exception is India, where molasses, a by-product of sugar cane processing, are used as feedstock for biofuel production.

The basic idea is to maximize the amount of land revenue that can be derived from the various uses of land whose supply is limited by a land constraint. The problem can be set up using a maximization framework. Beghin (2009) has shown that the supply of land to each of the individual uses of land is a function of the relative land price and land constraint[7].

The market for land is composed of demand and supply of land. Land is a primary input in production and accounted within the value added of forestry, pasture and agricultural crops production. In each of these sectors a demand function for land is specified.

In the model land is specified as a multi-level CET nest of various uses of land. At the top level, land is supplied to forestry, pasture, and agriculture crops. Land used in agricultural crops is divided into various uses. At the second nest level, land used in agricultural crops is divided to grains and oilseeds, sugar, rice, and other crops. At the third level, land used in grains and oilseeds is further disaggregated to corn, wheat, other coarse grains, and oilseeds.

There are nine separate demand functions for land, each with a corresponding land supply functions. Each pair of demand for and supply of land determines a land market that is cleared by a land price. This disaggregation is critical in the biofuel analysis because it captures the

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[7] Mathematically, the maximization problem generates the following system of equations

$$L_i \;=\; \theta_i^{\sigma^{CET}} A \cdot \left[\frac{PP}{R_i}\right]^{\sigma^{CET}}$$

This is the supply of land, where R_i is return to land use i; PP composite of all R_i defined in (b); and A is the overall land constraint in (c). All Greek letters represent shift and share parameters.

$$PP \;=\; \left[\sum_i \theta_i^{\sigma^{CET}} R_i^{1-\sigma^{CET}}\right]^{\frac{1}{1-\sigma^{CET}}}$$

This is the composite price of all R_i

$$A \;=\; \left[\sum_i \theta_i L_i^{\frac{1-\sigma^{CET}}{\sigma^{CET}}} R_i^{1-\sigma^{CET}}\right]^{\frac{\sigma^{CET}}{1-\sigma^{CET}}}$$

This is the land constraint where A is fixed.

differences in land returns, which drive the allocation of land to various uses. For example, if subsidies and other related production incentives are implemented to support a corn ethanol program, the return to land planted with corn will increase relative to other land uses. This will attract corn cultivation and trigger substitution from other land uses to land production. The substitution is done through a CET transformation function. The degree of land reallocation to various uses will depend upon the magnitude of the transformation elasticity in the CET function.

To implement the land module, land is decomposed into 18 agro-ecological zones (AEZs), which is available in the GTAP database. In each of the 18 AEZs, there is land supply to each of the nine uses.