[*Preliminary Draft – Do Not Cite or Quote*]

# Analyzing Global Implications of U.S. Biofuels Polices in a Dynamic General Equilibrium Framework

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Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2013 AAEA & CAES Joint Annual Meeting, Washington, DC, August 4-6, 2013.

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## Introduction

Biofuels have continued to gain momentum over the last decade due to growing worldwide interest in achieving energy security and climate change mitigation. The first generation biofuels produced mainly from agricultural sources have experienced unprecedented growth in recent years. The U.S. has emerged as the leading producer of biofuels, with 13.2 billion gallons of corn-ethanol and more than one billion gallons of biodiesel in 2012. The U.S. Congress has established a renewable fuel standard (RFS) rule that mandates annual production of 36 billion gallons of biofuels by 2022 (USEPA, 2010), which includes 16 billion gallons of second generation cellulosic biofuels. Currently, only 100 million gallons of cellulosic biofuels production capacity is under construction in the U.S. which mainly uses energy grasses and crop residue as their feedstock. As the International Energy Agency (IEA) reports, around 52 countries together produced more than 28 billion gallons of different types of biofuels for transportation in 2010. The mandates implemented in these countries would require a total production of 60 billion gallons by 2022. Large scale production of biofuels results in far-reaching intended and unintended consequences on the economy and environment.

Previous studies on examining the economywide impact of biofuels have focused mainly on first generation biofuels (Birur et al. (2008), Hertel et al. (2010a, 2010b), Taheripour et al. (2010), Golub et al. (2012), and Dimaranan and Laborde (2012)). In this study we adopt a recursive dynamic computable general equilibrium (CGE) framework based on the Global Trade Analysis Project (GTAP) data base and a suite of models. The global nature of the GTAP modeling framework helps in assessing worldwide trends in use of biofuels and petroleum products as several national governments have implemented mandates or targets for use of biofuels for transportation. For instance, the first application of the GTAP model on biofuels was by Hertel et al. (2010a) studied the impacts of U.S. and EU biofuel mandates on global land use and land cover change. Their study revealed that the U.S. and EU biofuel mandates would have significant impacts on the U.S. corn market and the oilseeds markets across the world. The study found that share of corn going to ethanol production in the U.S. could more than double from the 2006 levels, and the share of oilseeds going to biodiesel production in the EU could triple.

Furthermore, the study found that the impacts of the combined biofuels mandates in the U.S. and EU would have a much greater impact on the third world economies, resulting in sharp increases in cropland cover in Latin America, Africa and Oceania - most noticeably at the expense of pasturelands, as well as commercial forests. Hertel et al. (2010b) focused their analysis on 15 billion gallons of corn-ethanol production in the U.S. by 2015 and the resulting greenhouse gas (GHG) emission from land use and land cover change. The study revealed that direct and indirect land conversion would release 27 grams of $CO_2$ per MJ of corn-ethanol per year, over 30 years of ethanol production.

Taheripour et al. (2010) analyzed the importance of accounting for by-products of biofuels in a CGE model and found that economic and environmental impacts are significantly mitigated. Recently, Tyner et al. (2010) included marginal lands and productivity estimates for the potential new cropland based on a biophysical model, and analyzed the impact of 15 billion gallons of corn-ethanol production for 2015. With the assumption on growth in crop yield and population, the study found 14.5 grams of $CO_2$ per MJ of ethanol production. Since these studies are based on general equilibrium modeling approach, they help in accounting for the full impact of biofuels production including displacement of petroleum products on a country's balance of trade and domestic economic activities.

Studies on longer term implications such as Golub et al. (2012) adopted the recursive dynamic version of the GTAP model called Gdyn-E-AEZ to study the global land-use change due to impact of policies such as GHG mitigation by cleaner agricultural production practices, and also due to expanded biofuels production. Another study by Dimaranan and Laborde (2012) study the impacts of US and EU biofuel mandates by using a recursive dynamic model called MIRAGE-BIOF which allows for substitutability between different sources of energy. Though these dynamic models are helpful in estimating long run implications of biofuels policies, they do not include the emerging second generation biofuels. This study focuses on examining the longer-term global implications of complete execution of U.S. RFS2 policy which includes both first and second generation biofuels.

## 2. Study Approach

In this study, we develop GDyn-E-BIO, a multi-region, multi-sector, recursive dynamic CGE model by adapting the GDyn-E-AEZ model (Golub et al., 2012) which was developed by combining comparative static versions of the GTAP-E (Burniaux and Truong, 2002) and GTAP-BIO (Birur et al. 2008; Taheripour et al. 2010) models and the recursive dynamic GDyn (Ianchovichina and McDougall, 2001). The GDyn (dynamic GTAP) model is a recursive dynamic CGE model where the agents base their decisions on adaptive expectations, with international capital mobility and endogenous capital accumulation. The dynamics in the GDyn model comes from capital accumulation, labor productivity, and other exogenous macro variables such as GDP and population growth. Following the GTAP-BIO model, we further modify the nested constant elasticity of substitution (CES) production structure of firms to allow for production of six first and two second generation biofuels by utilizing their respective feedstock crops along with other factor inputs, and complement with the petroleum products sector. We allow for substitution of all the transportation fuels in the household consumption structure with calibrated elasticity of substitution in each region.

The land supply structure follows a 18 Agro-Ecological Zone (AEZ) level nested constant elasticity of transformation (CET) function where the land is first allocated across three cover types (cropland, pastureland, forestland) and in the second tier cropland is allocated across alternate crops including switchgrass. Compared to previous studies, the detailed incorporation of explicit crops in this study helps in precisely identifying the change in cropping pattern and distribution. Based on secondary data, we develop a historical (2004-2010) baseline and forward-looking (2010-2050) baseline that includes macro-economic variables and agriculture specific features of the economy over the projected period. We validate the model by reproducing key features of the U.S. biofuels economy in 2010.

## 3. Developing the Data Base

A key input for CGE modeling of biofuels is the data base. For incorporating biofuels into the Gdyn-E-BIO model, we use the GTAP version 7.1 data base, which comprises 57 sectors and 112 global regions pertaining to the global economy in 2004. Since the GTAP data base does not explicitly include some of the major feedstock crops, biofuels, and by-products, we introduce these sectors into the data base by breaking out the existing GTAP sectors. Biofuels are produced mainly from feedstocks such as grain, sugar-crops, oilseeds, and cellulosic feedstock. We introduce four types of ethanol (two starch and two sugar; additional starch-based ethanol pathways and cellulosic feedstocks will enter in future years rather than being incorporated within the base year database) and three types of biodiesel based on the types of feedstock used to produce them in 2004. Since several feedstock crops in the GTAP data base are aggregated, we first needed to break out some of the important crops and then introduce the biofuels and their by-products.

Table 1 below depicts the new and existing sectors that are explicitly represented in the revised GTAP data base (the complete list of sectors is given in Table A2 in Appendix). For instance, corn-ethanol is generated by splitting the food products sector (ofd) which receives the inputs from corn (corn) and soy-biodiesel is generated from the vegetable oils and fats (vol) sector which absorbs inputs from the oil-seed sectors, the sugarcane based ethanol was broken out from chemicals sector (crp) with the input from sugar cane sector, and so on.

**Table 1. Splitting of Biofuels and related Sectors from the Existing GTAP Sectors.**

| *New Sectors* | *Existing sectors used to Split* | *Final Sectors* |
|---|---|---|
| Corn | **gro** (cereal grains) | gro = **corn** + gron |
| Soybean<br>Rapeseed<br>Palm | **osd** (oilseeds)<br>**osd** (oilseeds)<br>**osd** (oilseeds) | osd = **soyb** + **rapm + plmk** + osdn |
| Sugarcane<br>Sugarbeet | **c_b** (sugar cane, beet)<br>**c_b** (sugar cane, beet) | c_b = **srcn** + **srbt** |
| Corn-Ethanol<br>Wheat-Ethanol | **ofd** (food products nec)<br>**ofd** (food products nec) | ofd = **Tcet** + **weth** + ofdn |
| Soy-Biodiesel<br>Rape-Biodiesel<br>Palm-Biodiesel | **vol** (vegetable oils)<br>**vol** (vegetable oils)<br>**vol** (vegetable oils) | vol = **sybd** + **rpbd** + **plbd** + voln |
| Scane-Ethanol<br>Sbeet-Ethanol | **crp** (chemicals)<br>**crp** (chemicals) | crp = **scet** + **sbet** + crpn |
| DDGS<br>Oil-meal | Joint product of Corn-Ethanol<br>Joint product of vegetable-oil | Tcet = ceth + **ddgs**<br>voln = volr + **omel** |
| Corn Residue<br>CellEth_CR | Corn (grain & residue)<br>New cellulosic ethanol (enzymatic) | CornGr + Corn Resi<br>CellEth_CR |
| Switchgrass<br>CellEth_SG | New Switchgrass crop<br>New cellulosic ethanol (thermochemical) | SwtchGrass<br>CellEth_SG |
| Miscanthus<br>CellBiod_MC | New Switchgrass crop<br>New cellulosic biodiesel (Fischer-Tropsch) | Miscanthus<br>CellBiod_MC |

For any new sector, an existing sector is split based on input-output flow in a particular region. The by-products such as distillers dried grains with solubles (DDGS) are introduced such that the total corn-ethanol industry (Tcet) jointly produces both corn-ethanol (ceth) and DDGS (ddgs). Because the vegetable oil (vol) sector in the GTAP data base also included oil-meal, we modified the data to introduce oil-meal as a joint product of rest of vegetable-oil (volr) sector. These byproducts are allowed to sell as intermediate inputs in the livestock sectors.

For splitting the existing sectors in the GTAP data base, we used a utility called Splitcom, software developed by Horridge (2005). In order to split out a new sector in general, we used the following information on its share in the existing aggregated sector.

1. *Trade shares* – the trade shares are computed based on data on production, exports and imports across countries. Based on bilateral trade and tariff information on a new sector, the trade margins (surface, water, and air transport) are computed on the basis of margins in the existing sector.
2. *Row Shares* – the row shares show how consumption of the new sectors (e.g., biofuels, byproducts, etc.) flows through households, intermediate demands, and government demands. Initially all the biofuels are channeled to sell only to households in the data base, but this assumption can be relaxed to accommodate blending requirements in the petroleum sector.
3. *Column shares* – the column shares show the cost components involved in production of the new sectors. The cost structure of new crops and biofuels were obtained from various secondary sources listed in the next section.
4. *Cross shares* – cross shares are required if any of the new sectors also use the new commodities (typically required only if there is any own use in a given sector). The biofuels sectors were assumed have no own use, but the crops sectors were assumed to have a fraction of own use to meet the seed demand.

When these shares were computed for a given sector, attention was given to keep the social accounting matrix balanced as well as to avoid any negative flows across sectors and regions, which required a few relatively small changes in cost assumptions in some of the minor biofuels producing regions.

### 3.1 Data and Sources:

The share (weights) matrices are generated based on the secondary data and sources listed in Table 2. The share of new feedstock crop sectors are computed mainly based on FAO data on area, production, and price across all regions in 2004. The production value share of feedstock crops in the aggregate crop categories were used in determining the weights for splitcom. For example, share of corn was computed based on acreage and production value amongst the cereal grains basket which consists of corn, barley, sorghum, millet, mixed-grain, oats, and rye. Similar approach was used for oilseeds and sugar-crops.

**Table 2. Data and Sources used for Generating Shares of New Sectors.**

| *Data used* | *Units* | *Source* |
|---|---|---|
| Area, production, yield, and wholesale price of feed-grains and oilseeds in all countries - specifically:<br>Corn,<br>Soybean,<br>Rapeseed/Mustard/canola,<br>Palm(fruit & kernel) | Hectares, metric tonnes, t/Ha, $/t, for 2004 and historical (1961-2009). Trade data in quantity and value. | U.N. Food and Agricultural Organization (FAO, 2010). |
| Vegetable oils production and trade for all countries. | Historical (1961-2009) trade data in quantity & value – Central Product Classification (CPC) and Harmonized Commodity Description and Coding System (HS) level data. | FAO (2010),<br>UN Comtrade (2010). |
| Supply, domestic use, trade of corn, oilseeds, sugar, livestock, dairy, poultry, for all countries.<br><br>Fuel use of feed grains. | Metric tonnes – historical (1960-2009).<br><br>Million bushels – historical (1980-2009) | Foreign Agricultural Service (FAS, 2010).<br><br>Economic Research Service (ERS, 2010a) |
| Biofuels production, trade, price. | Ktoe, million gallons, $/gallon. | International Energy Agency (IEA, 2010), Ethanol Renewable Fuels Association (RFA, 2010). |
| Production costs and returns of U.S. crops. | $/ planted acre. | ERS (2010b) |
| Sugar-ethanol production, trade, prices. | Thousand liters, Real/liter | UNICA (2010) |

| | | |
|---|---|---|
| By-products of biofuels – DDGS and vegetable oil-meal | Metric tonnes, $/t. | AgMrc, Neo-Nebraska prices, CME group, ddgs.umn. |
| Real and nominal exchange rates. | Local currency/ USD (historical 1970-2009). | ERS (2010c) |
| Cost of production, conversion factors, etc. for feedstocks, biofuels and by-products: | Processing models – costs and returns: | *Literature sources*: |
| corn, soybean, rapeseed | ($ per unit of production) | ERS (2010b) |
| palm | ($ per unit of production) | Ismail et al. (2003) |
| corn-ethanol & DDGS | ($ per unit of production) | Kwiatkowski et al. (2006) |
| sugar-ethanol | ($ per unit of production) | Tifanny and Eidman (2003) |
| soy-biodiesel | ($ per unit of production) | Faaij (2009),<br>Geller (1985) |
| rape-biodiesel | ($ per unit of production) | Haas et al. (2006) |
| palm-biodiesel | ($ per unit of production) | Frier and Roth (2007)<br>Canakci and Sanli (2008) |

### 3.2 Biofuels Production and Trade:

We obtained the biofuels production and trade data from the International Energy Agency (IEA, 2010) for 2004 and also for the latest available year, 2008. The original IEA data was available in energy terms (ktoe) for aggregated categories such as bio-gasoline, biodiesels, and other liquid biofuels. Also, the IEA source does not provide bilateral trade data on biofuels. Therefore, we utilized the knowledge from various other secondary sources and literature about the countries that are engaged in production of and trade in biofuels, the feedstock used, and also the geographic location of the countries that influence the bilateral trade. In the 2004 IEA data, production of biofuels was reported only in 24 countries, whereas the 2008 data indicated 46 producing countries. Since our biofuels modeling work requires true depiction of a future scenario, it is important to have some production in all the producing countries in the base data for use in the GTAP model. Therefore, we modified the 2004 IEA data so as to include all the 46 producing countries with the additional countries having a small amount of production and trade. After categorizing different types of biofuels, the physical data on energy basis was converted to million gallons and then to million dollars based on the prices for ethanol and biodiesel. The production of different types of biofuels for 2004 and 2010 in million gallons is presented below in Table 3. As seen from the table, global production of corn-ethanol was 4.05 billion gallons in 2004, followed by sugarcane-ethanol (3.76 bg), rape-biodiesel (0.56 bg), wheat-ethanol (0.23 bg), palm-biodiesel (0.13 bg), sugar-beet ethanol (0.13 bg), and soy-biodiesel (0.06 bg). Dramatic changes in production can be seen by 2010.

The production of DDGS is assumed at the rate of 6.07 lbs per 1 gallon of ethanol produced (i.e., 1 bushel of corn produces 2.8 gallons of ethanol and 17 lbs of DDGS). In 2004, the production of DDGS was about 9.77 million tonnes while only 0.74 million tonnes were exported. But the U.S. exports grew more than 11 times (8.3 million tonnes) in 2010, with China being the major importer, followed by Mexico, Canada and 15 other significant importing regions. This trade pattern was followed to incorporate the 2004 data on DDGS.

The oil-meal data was broken-out from the original vegetable-oil sector since it was inherent in the original GTAP data base. The vegetable oil sales (domestic and imported) into the livestock sectors were separated as oil-meal and the bilateral-trade data was created based on vegetable trade in vegetable oil. Attention was paid to exclude the palm oil producing regions not to produce any oil-meal (as palm-cake is not consumed by livestock). About 98% of the oil-meal was allowed to sell as intermediate input in the livestock sectors (ctl, oap, rmk, sectors in Table A2).

## Table 3. Historical Production of different types of Biofuels (*million gallons*).

| | Country | Production in 2004 | | | | | | | Production in 2010[1] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Corn-Ethanol | Wheat-Ethanol | Soy-Biodiesel | Rape[2]-Biodiesel | Palm-Biodiesel | Sugarcane-Ethanol | Sugarbeet-Ethanol | Corn-Ethanol | Wheat-Ethanol | Soy-Biodiesel | Rape[2]-Biodiesel | Palm-Biodiesel | Sugarcane-Ethanol | Sugarbeet-Ethanol |
| 1 | Australia | | 5.24 | | 2.69 | | | | | 41.19 | | 14.97 | | | |
| 2 | Austria | | 4.19 | | 3.37 | | | 19.23 | | 24.55 | | 49.42 | | | 61.36 |
| 3 | Belgium | | 2.62 | | 6.73 | | | 5.24 | | 5.65 | | 97.43 | | | 14.58 |
| 4 | Canada | 24.14 | 24.14 | | | | | | 150.92 | 150.92 | | | | | |
| 5 | Czech Rep. | | 4.19 | | 25.96 | | | | | 24.32 | | 24.60 | | | |
| 6 | Denmark | | | | 19.64 | | | 2.62 | | | | 32.64 | | | 4.35 |
| 7 | Finland | | | | 1.68 | | | | | | | 3.58 | | | |
| 8 | France | | 27.17 | | 89.71 | 29.90 | | | | 258.94 | | 445.19 | 148.40 | | |
| 9 | Germany | | 21.79 | | 235.47 | 78.49 | | 10.35 | | 274.59 | | 793.67 | 264.56 | | 686.12 |
| 10 | Greece | | | | 3.37 | | | | | | | 23.17 | | | |
| 11 | Hungary | | 4.19 | | 6.73 | | | | | 21.66 | | 47.49 | | | |
| 12 | Ireland | | | | 2.69 | | | 2.62 | | | | 6.92 | | | 1.43 |
| 13 | Italy | | 4.19 | | 85.98 | | | 2.62 | | 31.69 | | 230.94 | | | 9.16 |
| 14 | Korea | | | 1.54 | | | | | | | 60.44 | | | | |
| 15 | Luxembourg | | | | | | | | | | | | | | |
| 16 | Netherlands | | 4.19 | | 3.37 | | | 10.48 | | 2.55 | | 29.62 | | | 23.97 |
| 17 | Norway | | | | | | | | | | | | | | |
| 18 | Poland | | 7.05 | | | | | | | 32.27 | | 93.82 | | | 2.97 |
| 19 | Portugal | | | | 6.73 | | | 2.62 | | | | 53.98 | | | 1.93 |
| 20 | Slovak Rep. | | 4.19 | | 3.71 | | | | | 20.89 | | 37.28 | | | |
| 21 | Spain | | 38.88 | | 34.22 | | | | | 119.53 | | 75.27 | | | |
| 22 | Sweden | | 62.57 | | 2.41 | | | 8.93 | | 146.84 | | 53.40 | | | 61.38 |
| 23 | Switzerland | | 1.05 | | 0.77 | | | | | 1.05 | | 3.12 | | | |
| 24 | Turkey | | 2.62 | | 2.69 | | | | | 3.52 | | 3.28 | | | |
| 25 | United Kingdom | | 5.24 | | 6.73 | | | | | 24.18 | | 95.93 | | | |
| 26 | United States | 3546.43 | | 36.19 | | | | 6.95 | 12245.25 | | 893.38 | | | | 58.41 |

Continued…

| Country | | Production in 2004 | | | | | | | Production in 2010[1] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Corn-Ethanol | Wheat-Ethanol | Soy-Biodiesel | Rape-Biodiesel | Palm-Biodiesel | Sugarcane-Ethanol | Sugarbeet-Ethanol | Corn-Ethanol | Wheat-Ethanol | Soy-Biodiesel | Rape-Biodiesel | Palm-Biodiesel | Sugarcane-Ethanol | Sugarbeet-Ethanol |
| 27 | Argentina | | | 6.50 | | | | | | | 288.10 | | | | |
| 28 | Belarus | | | | 1.68 | | | | | | | 2.48 | | | |
| 29 | Brazil | | | 7.01 | | | 3664.94 | | | | 436.46 | | | 7889.22 | |
| 30 | Bulgaria | | | | 1.80 | | | 1.05 | | | | 3.11 | | | 0.97 |
| 31 | China | 477.00 | | 6.69 | | | | 53.00 | 562.65 | | 124.23 | | | | |
| 32 | Colombia | | | | | | 5.24 | | | | | | | 72.53 | |
| 33 | Croatia | | | | 0.67 | | | | | | | 1.24 | | | |
| 34 | Cuba | | | | | | 29.93 | | | | | | | 12.57 | |
| 35 | Cyprus | | | | 1.50 | | | | | | | 2.17 | | | |
| 36 | India | | | | | | 53.98 | | | | | | | 418.53 | |
| 37 | Indonesia[3] | | | | | 5.00 | 1.05 | | | | | | 24.92 | 0.35 | |
| 38 | Latvia | | | | 1.64 | | | 1.05 | | | | 8.70 | | | 4.22 |
| 39 | Lithuania | | | | 3.37 | | | 2.62 | | | | 20.19 | | | 5.99 |
| 40 | Macedonia | | | | 0.67 | | | | | | | 0.31 | | | |
| 41 | Malaysia[3] | | | | | 10.00 | | | | | | | 92.06 | | |
| 42 | Paraguay | | | | | | 2.62 | | | | | | | 15.84 | |
| 43 | Philippines | | | | | 3.37 | | | | | | | 17.39 | | |
| 44 | Romania | | 2.62 | | 6.73 | | | | | 31.91 | | 37.27 | | | |
| 45 | Slovenia | | | | 0.67 | | | | | | | 2.49 | | | |
| 46 | Thailand | | | | | 6.73 | 5.24 | | | | | | 123.92[4] | 90.13 | |
| | **WORLD** | 4047.57 | 226.13 | 57.92 | 563.51 | 133.49 | 3763.00 | 129.37 | 12958.83 | 1216.25 | 1802.62 | 2293.67 | 671.25 | 8499.17 | 936.86 |

Note: The major source of production data for 2004 is IEA (2010), but the biofuels are categorized by feedstock based on various secondary sources such as EBB (2010), EIA (2010), FAPRI (2010), and RFA (2010).

[1] Production in 2010 is estimated based on IEA data available for 2008 and other secondary sources.

[2] Rape biodiesel includes *Brassica sp.* derivatives such as rapeseed, mustard, and canola.

[3] Palm-biodiesel data in Malaysia and Indonesia in 2004 is assumed as 10 and 5 m. gal., respectively, since the data for these two countries were available starting only from 2006.

[4] Production of biodiesel in Thailand includes both palm as well as coconut feedstocks.

### 3.3 A Snap Shot of the Data Base:

This section gives an overview of the data base with a few selected snapshots. Table 4 illustrates the domestic and export sale of all the crops categories in a few selected regions in the new data base. As seen from the table in value terms ($ million), about 28% of the corn grown in the U.S. is exported, while the export of soybean was 37% in 2004. While the value of sugar-cane production in Brazil was $ 3.2 billion, Germany and France produced sugar-beet worth $1.63 and 1.4 billion, respectively. Rapeseed-Mustard was the major oilseed crop grown in Germany and 83% of the output was consumed domestically. Most of the food crops grown in China are domestically consumed. Production of palm in Indonesia was about $4.5 billion (not included in the table).

Another slice of the data base is presented in Table 5, which demonstrates the disposition of the major feedstock crops in some selected countries. For instance in the U.S., about 13% of corn produced goes for ethanol production in 2004, while 48% is sold to the feed sector, 28% for exports, and 11% for other uses. Similarly, about 37% of U.S. soybeans output goes to vegetable oils sector and an equivalent portion for exports. The remaining 25% of soybean output goes for food and other uses (the production of soy-biodiesel mainly utilizes the vegetable oil in the U.S.). Whereas, in Germany about 20% of rapeseed-mustard output goes to vegetable oil sector, 27% to biodiesel sector, 36% for other uses and about 17% is exported. In Brazil, nearly 50% of the sugarcane output is sold for sugar-production and 35% for ethanol production, while 15% is sold for other uses (own use, beverages, food, etc.).

The second generation biofuels include corn-residue based ethanol by biochemical process, switchgrass based ethanol by thermochemical process, and miscanthus based biodiesel by Fischer-Tropsch process. For tractability, we aggregate the data base to comprise 25 regions (Table A1) and 45 sectors (Table A2), focusing on agricultural and other sectors most likely to be directly impacted by expanded biofuels production.

## Table 4. Domestic and Export Sale of Crops in Selected Regions the GTAP-Biofuels Data Base

*(2004 $ millions)*

| Crops | USA | | Brazil | | Germany | | France | | China | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Dom* | *Export* | *Dom* | *Export* | *Dom* | *Export* | *Dom* | *Export* | *Dom* | *Export* |
| Paddy rice | 1024.8 | 516.5 | 2411.1 | 0.4 | 5.9 | 5.0 | 28.3 | 30.8 | 14342.5 | 58.6 |
| | *66.5%* | *33.5%* | *100.0%* | *0.0%* | *54.2%* | *45.8%* | *47.8%* | *52.2%* | *99.6%* | *0.4%* |
| Wheat | 571.0 | 6113.5 | 246.1 | 298.6 | 2416.9 | 869.8 | 4046.3 | 2460.1 | 6909.0 | 138.3 |
| | *8.5%* | *91.5%* | *45.2%* | *54.8%* | *73.5%* | *26.5%* | *62.2%* | *37.8%* | *98.0%* | *2.0%* |
| Corn | 15647.8 | 6105.3 | 2572.1 | 805.2 | 462.8 | 135.1 | 792.6 | 1162.4 | 6642.3 | 370.7 |
| | *71.9%* | *28.1%* | *76.2%* | *23.8%* | *77.4%* | *22.6%* | *40.5%* | *59.5%* | *94.7%* | *5.3%* |
| Rest of Cereal Grains | 880.4 | 1502.8 | 88.0 | 47.9 | 1600.8 | 497.1 | 567.3 | 1061.4 | 378.6 | 68.2 |
| | *36.9%* | *63.1%* | *64.8%* | *35.2%* | *76.3%* | *23.7%* | *34.8%* | *65.2%* | *84.7%* | *15.3%* |
| Vegetables, fruit, nuts | 34045.2 | 7293.7 | 1904.7 | 833.3 | 3019.4 | 1354.2 | 4840.4 | 2935.8 | 99237.6 | 2709.9 |
| | *82.4%* | *17.6%* | *69.6%* | *30.4%* | *69.0%* | *31.0%* | *62.2%* | *37.8%* | *97.3%* | *2.7%* |
| Soybean | 9818.9 | 5791.1 | 7102.4 | 2259.6 | 0.01 | 0 | 29.4 | 0.5 | 3528.8 | 293.1 |
| | *62.9%* | *37.1%* | *75.9%* | *24.1%* | *100.0%* | | *98.3%* | *1.7%* | *92.3%* | *7.7%* |
| Rape-Mustard | 31.3 | 757.5 | 2.5 | 84.5 | 1159.5 | 236.8 | 621.7 | 372.2 | 1342.6 | 157.8 |
| | *4.0%* | *96.0%* | *2.8%* | *97.2%* | *83.0%* | *17.0%* | *62.6%* | *37.4%* | *89.5%* | *10.5%* |
| Palm | 0 | 0 | 65.0 | 111.2 | 0 | 0 | 0 | 0 | 155.4 | 24.3 |
| | | | *36.9%* | *63.1%* | | | | | *86.5%* | *13.5%* |
| Rest of Oilseeds | 5.4 | 1085.7 | 677.2 | 3164.4 | 9.8 | 8.7 | 389.8 | 303.7 | 134.5 | 129.9 |
| | *0.5%* | *99.5%* | *17.6%* | *82.4%* | *52.9%* | *47.1%* | *56.2%* | *43.8%* | *50.9%* | *49.1%* |
| Sugarcane | 856.6 | 0 | 3199.2 | 0 | 0 | 0 | 0 | 0 | 737.7 | 0 |
| | *100.0%* | | *100.0%* | | | | | | *100.0%* | |
| Sugarbeet | 1174.4 | 0 | 0 | 0 | 1631.0 | 1.4 | 1402.3 | 5.2 | 28.7 | 0 |
| | *100.0%* | | | | *99.9%* | *0.1%* | *99.6%* | *0.4%* | *100.0%* | |
| Plant-based fibers | 2473.7 | 4311.2 | 840.8 | 435.8 | 14.7 | 40.2 | 102.2 | 61.4 | 4784.4 | 21.2 |
| | *36.5%* | *63.5%* | *65.9%* | *34.1%* | *26.8%* | *73.2%* | *62.5%* | *37.5%* | *99.6%* | *0.4%* |
| Other Crops | 23068.3 | 2672.1 | 4529.5 | 3404.8 | 11303.0 | 1421.3 | 20639.0 | 872.7 | 802.9 | 1428.2 |
| | *89.6%* | *10.4%* | *57.1%* | *42.9%* | *88.8%* | *11.2%* | *95.9%* | *4.1%* | *36.0%* | *64.0%* |

**Table 5. Disposition of Feedstock in a few Selected Regions in the GTAP-Biofuels Data Base**

*(2004 $ millions)*

| *Sale of **Corn** in the **US*** | $ million | % | *Sale of **Soybean** in the **US*** | $ million | % |
|---|---|---|---|---|---|
| Corn-Ethanol | 2804.77 | 12.89 | Soy-Biodiesel | 31.25 | 0.20 |
| Feed Sector | 10432.33 | 47.96 | Veg-Oil & Meal Sector | 5887.12 | 37.71 |
| Food & Other uses | 2410.64 | 11.08 | Food & Other uses | 3900.53 | 24.99 |
| Exports | 6105.27 | 28.07 | Exports | 5791.12 | 37.10 |
| **Total** | **21753.01** | 100.00 | **Total** | **15610** | 100.00 |
| *Sale of **Rapeseed** in **Germany*** | $ million | % | *Sale of **Sugarcane** in **Brazil*** | $ million | % |
| Vegetable Oil Sector | 277.76 | 19.89 | Sugar Sector | 1587.47 | 49.62 |
| Rape-Biodiesel | 374.49 | 26.82 | Sugarcane-Ethanol | 1119.21 | 34.98 |
| Other uses | 507.20 | 36.33 | Other uses | 492.52 | 15.40 |
| Export | 236.75 | 16.96 | **Total** | **3199.19** | 100.00 |
| **Total** | **1396.21** | 100.00 | | | |

### 3.4 Development of Dynamic Baseline (2010-2050):

The table below lists the projections of variables that constitute a dynamic baseline. The main variables needed for biofuels policy analysis are GDP growth and changes in energy consumption. Most of these data come from the World Energy Outlook through 2030. After 2030, population projections and assumptions about labor productivity growth are used to estimate GDP growth. Assumed changes in energy intensity per dollar of GDP then gives the energy consumption trends. We also developed the projections on technological change in agricultural production based on Total Factor Productivity (TFP) growth rates as offered by Ludena (2004) for the agricultural and livestock sectors.

**Table 6. Data and Sources of the Dynamic Baseline Variables.**

| ***Variables*** | ***Units*** | ***Data Sources*** |
|---|---|---|
| Population | millions | Population projections (U.N. ESA, 2008) |
| GDP | billion 2007$ | Projections from *World Energy Outlook 2010* (IEA, 2010). Historical from CIA |

| | | |
|---|---|---|
| | | *World Fact Book* (2009). |
| Energy Consumption (coal, electricity, natural gas, petroleum) | Quad Btu | *World Energy Outlook 2010* (IEA, 2010) |
| Energy Prices – limited data (coal, crude oil, natural gas) | $/MMBtu | *World Energy Outlook 2010* (IEA, 2010) |
| Electricity generation (by source) | billion kWh | *World Energy Outlook 2010* (IEA, 2010) |
| GHG emissions – non-energy (CO2, CH4, N20, HFC, PFC, SF6) | Mmt CO2e | Projections from U.S. EPA, 2006. (historical data from EPA *GHG Inventory*) |
| Agricultural production and food consumption | billion 2007$ | Population projections (U.N. ESA, 2008) |

**4. Experimental Design:**

In this study, we focus on implementing the U.S. RFS2 policy. Starting from the base year 2010, we implement the 2022 U.S. biofuels mandate which includes 15 bg of corn-ethanol, 16 bg of cellulosic biofuels combining corn-residue, switchgrass and miscanthus feedstock, and 5 bg of advanced biofuels combining soy-biodiesel, rape-biodiesel, palm-biodiesel, sugarcane and sugarbeet ethanol. Any import of biofuels into the U.S. subjected to RFS2 implementation would adjust depending on the price changes and trade restrictions.

**Table 7: Volume Requirements under U.S. RFS2 (billion gallons).**

| Year | Conventional Biofuel: Corn-ethanol | Advanced Biofuel: Cellulosic Biofuel | Advanced Biofuel: Biomass based Diesel | Advanced Biofuel: Unspecified | Total |
|---|---|---|---|---|---|
| 2010 | 11.24 | 0.10 | 0.65 | 0.96 | 12.50 |
| 2011 | 12.07 | 0.25 | 0.80 | 0.83 | 13.45 |
| 2012 | 12.83 | 0.50 | 1.00 | 0.87 | 14.63 |
| 2013 | 13.42 | 1.00 | 1.00 | 1.13 | 15.89 |
| 2014 | 14.09 | 1.75 | 1.00 | 1.31 | 17.43 |
| 2015 | 14.79 | 3.00 | 1.00 | 1.71 | 19.71 |
| 2016 | 15.00 | 4.25 | 1.00 | 2.00 | 21.44 |
| 2017 | 15.00 | 5.50 | 1.00 | 2.50 | 23.17 |
| 2018 | 15.00 | 7.00 | 1.00 | 3.00 | 25.15 |
| 2019 | 15.00 | 8.50 | 1.00 | 3.50 | 27.14 |
| 2020 | 15.00 | 10.50 | 1.00 | 3.50 | 29.10 |
| 2021 | 15.00 | 13.50 | 1.00 | 3.50 | 32.08 |
| 2022 | 15.00 | 16.00 | 1.00 | 4.00 | 35.06 |

5. Preliminary Results:

Our prospective analysis indicates substantial use of crops in the biofuels sectors due to RFS implementation. Though the increased demand for feedstock crops displaces crops away from food and feed sectors, it also substantially increases production and acreage in the U.S. and other regions of the world. The resulting increased demand for additional cropland leads to degradation of pastureland and deforestation globally, contributing to indirect land use change due to RFS implementation. We use the results from land cover change and convert to $CO_2$e emissions based on carbon conversion factors from Houghton and Hackler (2001) and Winrock International. The role of RFS2 mandates on change in food prices and consumption pattern over the long run across the regions are also examined.

[The work is under progress, the paper will be updated with the new results shortly].

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**Table A1. Aggregation of Regions in the Model.**

| *No.* | *Region-Code* | *Region Description* | *Comprising GTAP regions* |
|---|---|---|---|
| 1 | **USA** | United States | United States of America. |
| 2 | **EU27** | European Union 27 | Austria; Belgium; Cyprus; Czech Republic; Denmark; Estonia; Finland; France; Germany; Greece; Hungary; Ireland; Italy; Latvia; Lithuania; Luxembourg; Malta; Netherlands; Poland; Portugal; Slovakia; Slovenia; Spain; Sweden; United Kingdom; Bulgaria; Romania. |
| 3 | **Brazil** | Brazil | Brazil |
| 4 | **Canada** | Canada | Canada |
| 5 | **Mexico** | Mexico | Mexico |
| 6 | **Japan** | Japan | Japan |
| 7 | **China** | China, Hong Kong | China; Hong Kong. |
| 8 | **India** | India | India |
| 9 | **Russia** | Russia | Russia |
| 10 | **SAfrica** | South Africa | South Africa |
| 11 | **Argentina** | Argentina | Argentina |
| 12 | **Korea** | Korea | Korea |
| 13 | **Indonesia** | Indonesia | Indonesia |
| 14 | **Thailand** | Thailand | Thailand |
| 15 | **Malaysia** | Malaysia | Malaysia |
| 16 | **LAEEX** | Latin American Energy Exporters | Bolivia; Colombia; Ecuador; Paraguay; Venezuela. |
| 17 | **OthLACA** | Rest of LatinAmerica & Caribbean | Rest of North America; Chile; Peru; Uruguay; Rest of South America; Costa Rica; Guatemala; Nicaragua; Panama; Rest of Central America; Caribbean. |
| 18 | **RoWestEU** | Rest of Western Europe | Switzerland; Norway; Rest of EFTA; Ukraine. |
| 19 | **EastEU** | Rest of Eastern Europe | Rest of Europe, Rest of Eastern Europe; Albania; Belarus; Croatia. |
| 20 | **WestAsia** | Western Asia | Rest of Western Asia; Kazakhstan; Kyrgyzstan; Rest of Former Soviet Union; Armenia; Georgia; Iran; Turkey. |
| 21 | **RoSEAsia** | Rest of South and S.East Asia | Taiwan; Phillipines; Singapore; Vietnam; bangladesh; Rest of Oceania; Rest of East Asia; Cambodia; Lao People's Democratic Republic; Rest of South East Asia; pakistan; Sri Lanka; Rest of South Asia. |
| 22 | **NAfrica** | Northern Africa | Rest of North Africa; Egypt; Morocco; Tunisia. |
| 23 | **WCAfrica** | Western and Central Africa | Nigeria; Rest of Western Africa; Senegal; Central Africa; South-Central Africa. |
| 24 | **ESAfrica** | Rest of East Africa and SACU | Ethiopia; Madagascar; Malawi; Mauritius; Mozambique; Tanzania; Uganda; Zambia; Zimbabwe; Rest of Eastern Africa; Botswana; Rest of South African Customs Union. |
| 25 | **Oceania** | Oceania | Australia; New Zealand. |

**Table A2. Aggregation of Sectors in the Model**

| No. | Sector-code | Description | Comprising sectors |
|---|---|---|---|
| 1 | PaddyRice | Paddy rice | pdr |
| 2 | Wheat | Wheat | wht |
| 3 | CornGr | Corn Grain | Corn grain |
| 4 | rCrGrains | rest of Cereal Grains | gron |
| 5 | Soybean | Soybean | soyb |
| 6 | RapeMustd | Rape-Mustard | rapm |
| 7 | Palm | Palm-Kernel | plmk |
| 8 | rOilseeds | rest of Oilseeds | osdn |
| 9 | Sugarcane | Sugarcane | scane |
| 10 | Sugarbeet | Sugarbeet | sbeet |
| 11 | OthAgri | All other Crops | ocr, pfb, v_f |
| 12 | Ruminant | Ruminants | ctl, wol |
| 13 | NonRumnt | Non-Ruminants | oap |
| 14 | RawMilk | Dairy Industry | rmk |
| 15 | Forestry | Forestry | frs |
| 16 | OthPrimSect | OtherPrimary:Fishery & Mining | fsh, omn |
| 17 | ProcRumt | Processed Ruminant Meat: cattle,sheep,goats,horse | cmt |
| 18 | ProcNRumt | Processed NonRuminant Meat products nec | omt |
| 19 | FoodPdt | Food Products nec | ofdn |
| 20 | OthFoodPdts | Sugar; Beverages & tobacco pdts, Proc Rice, Dairy Pdts. | sgr, b_t, pcr, mil |
| 21 | Chemicals | rest of Chemical,rubber,plastic prods | crpn |
| 22 | En_Int_Ind | Energy intensive Industries | i_s, nfm |
| 23 | Oth_Ind_Se | Other industry and services | tex, wap, lea, lum, ppp, nmm, fmp, mvh, otn, ele, ome, omf, wtr, cns, trd, cmn, ofi, isr, obs, ros, osg, dwe, wtp, atp |
| 24 | RoadTrans | Transport nec | otp |
| 25 | Coal | Coal | coa |
| 26 | CrudeOil | Crude Oil | oil |
| 27 | Electricity | Electricity and heat | ely |
| 28 | Gas | Natural gas | gas, gdt |
| 29 | Oil_pcts | Petroleum, coal products | p_c |
| 30 | Wht_Eth1 | Wheat Ethanol | weth1 |
| 31 | Scn_Eth2 | Sugarcane Ethanol | sceth2 |
| 32 | Sbt_Eth2 | Sugarbeet Ethanol | sbeth2 |
| 33 | Soy_biod | Soy Biodiesel | sbiod |
| 34 | Rape_biod | Rape-Mustard Biodiesel | rbiod |
| 35 | Palm_biod | Palm-Kernel Biodiesel | pbiod |
| 36 | Corn_Eth1 | Corn Ethanol | ceth (Tcet) |
| 37 | DDGS | DDGS | ddgs (Tcet) |
| 38 | VegOil | Vegetable Oils | rvol (vol) |
| 39 | Oilmeal | Veg Oil-meal | omel (vol) |
| 40 | SwtchGrass | Switchgrass | swgrs |
| 41 | Miscanthus | Miscanthus | mscts |
| 42 | CornResi | Corn Residue | cornresi |
| 43 | CellEth_CR | Corn Residue based cellulosic ethanol (Enzymatic) | celleth_cr |
| 44 | CellEth_SG | Switchgrass based cellulosic ethanol (Thermochemical) | celleth_sg |
| 45 | CellBiod_MC | Miscanthus based cellulosic biodiesel (Fischer-Tropsch) | cellbiod_mc |

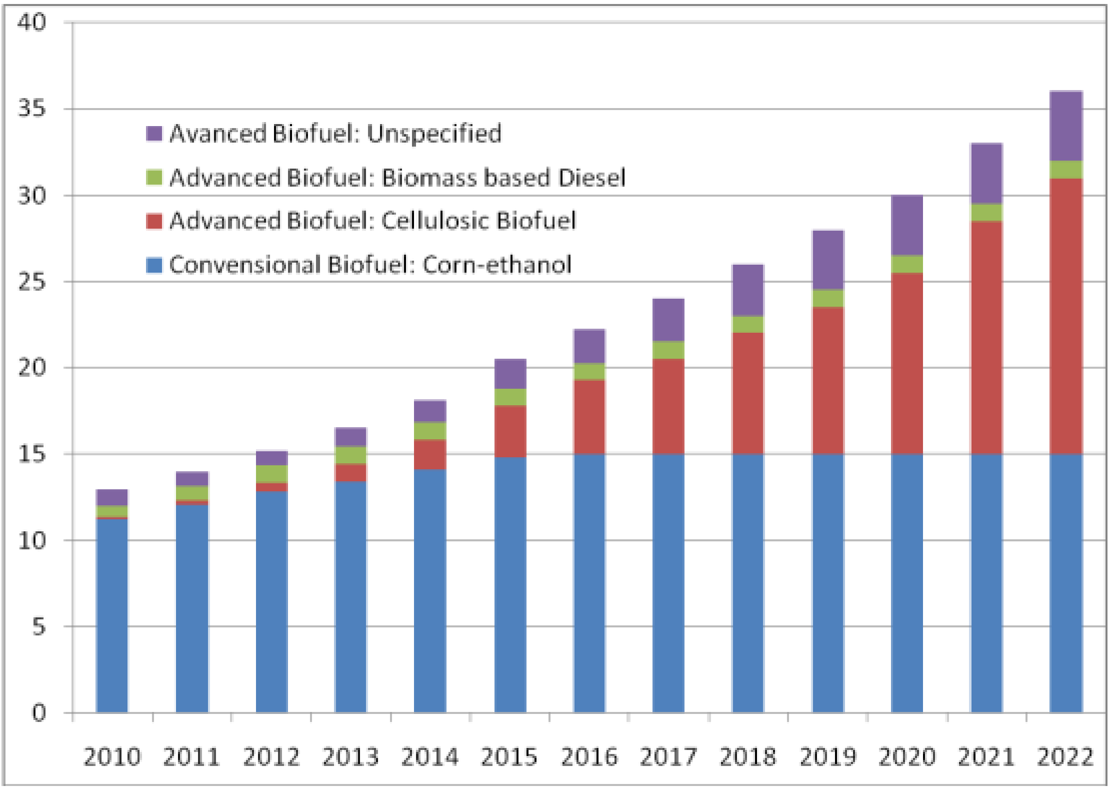


Figure A1. RFS2 volume requirements (billion gallons).
Source: USEPA (2010).

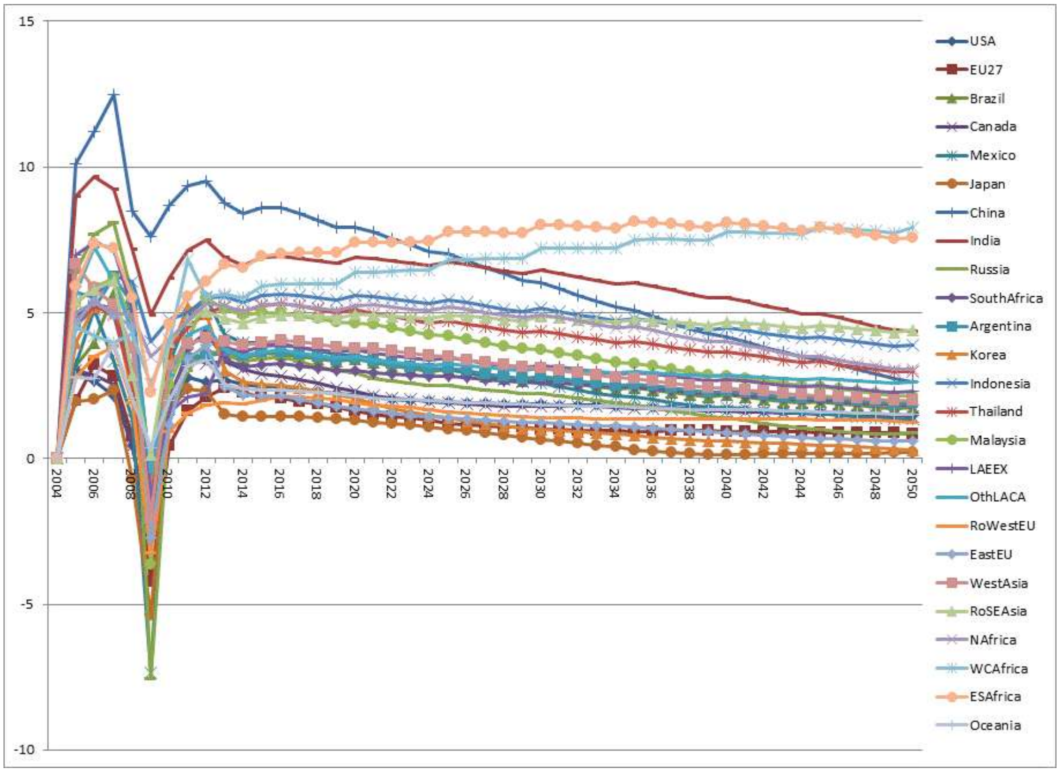


Figure A2. Baseline projections of growth in GDP (%).

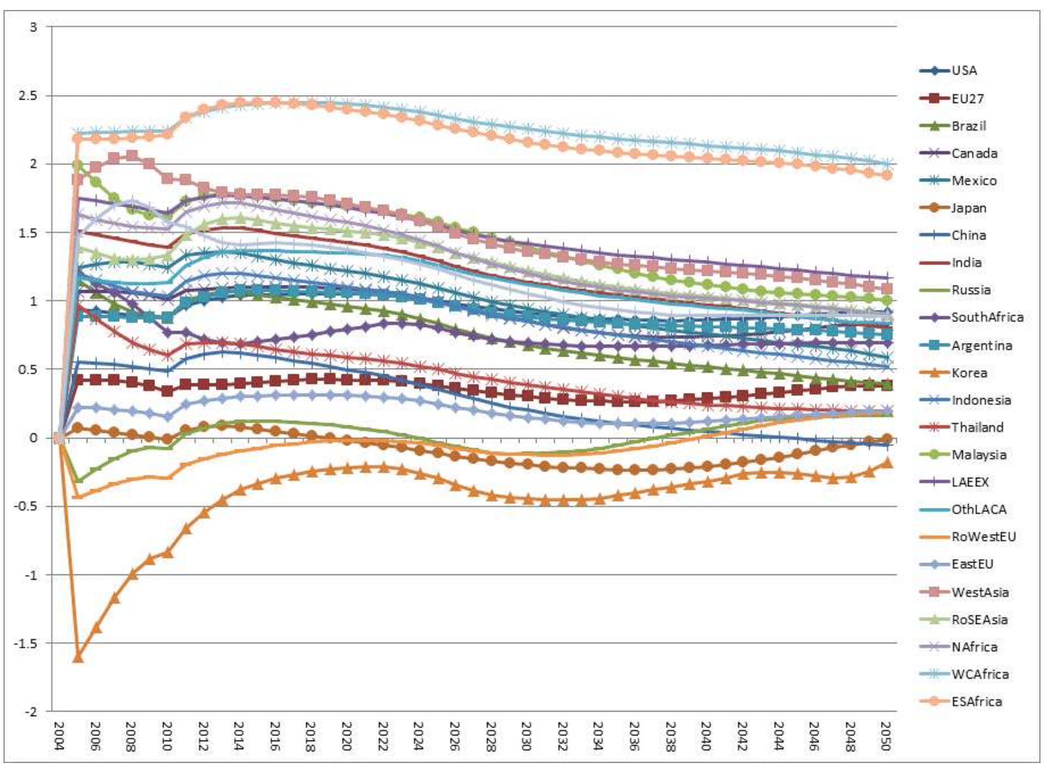


Figure A3. Baseline projections of growth in Population (%).

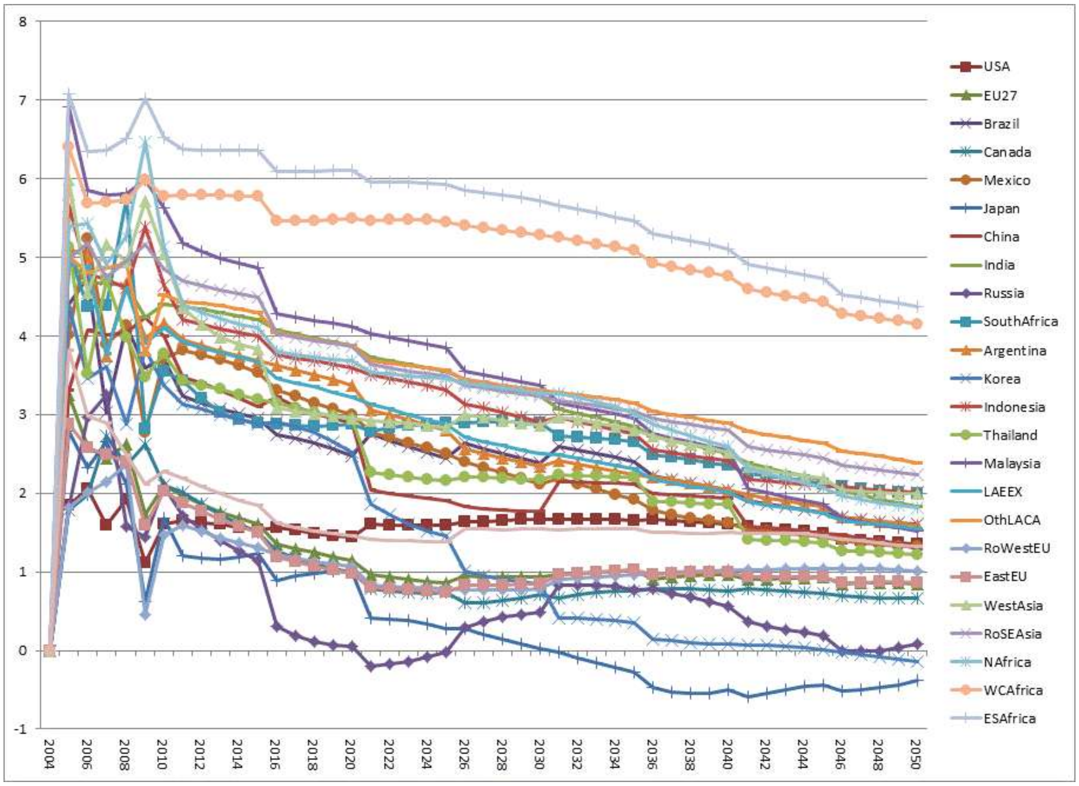


Figure A4. Baseline projections of growth in Skilled Labor (%).

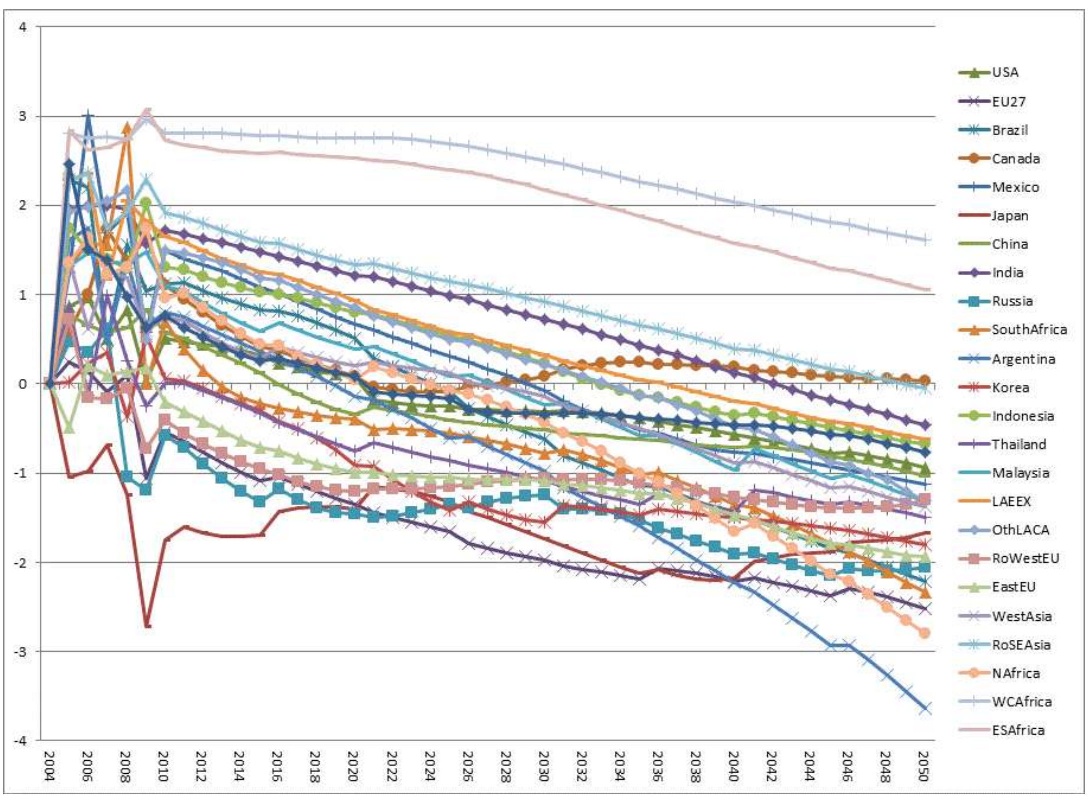


Figure A5. Baseline projections of growth in UnSkilled Labor (%).