Long-term Effects of the U.S. Renewable Fuel Standard on Wolrd Hunger

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1 Introduction

This paper will analyze the long-run effects of the U.S. Renewable Fuel Standards (RFSs) on world hunger. The "conventional biofuel" (including ethanol from grain) RFS allows for total annual biofuel requirements to be satisfied by use of 15 billion gallons of renewable fuel by 2015, and the "advanced biofuel" (including biodiesel and cellulosic ethanol) RFS requires annual use of 21 billion gallons by 2022. Increasing use of food commodities for fuel production understandably raises concerns that food prices will increase and additional people will be pushed into hunger. Indeed, as biofuels production increased over the 2005 to 2008 period, the prices of related ag commodities increased substantially. However, the high level of short-run variability in ag markets, combined with the inherently long-run nature of the adjustments that increasing biofuels production will provoke, make extrapolation of recent events a poor guide to long-run equilibrium outcomes. This paper will characterize these long-run effects. This "food vs. fuel" debate has at times been quite contentious. Yet despite the high level of concern and interest in this issue, no work to date has attempted to systematically quantify the increases in food insecurity caused by increasing biofuel production.

This project employs a static computable general equilibrium (CGE) model of world trade. The model uses the Global Trade Analysis Project (GTAP) database, and employs a high level of disaggregation in the agricultural sectors relative to other large-scale CGE models. The model features extensions of the GTAP data which allow inclusion of grain, switchgrass, and corn stover-based ethanol production sectors. The individual components of the mandate (advanced and conventional) will be reflected in constraints on the different ethanol sectors. Changes in market variables will directly result from calculated equilibria, and food insecurity implications will stem from a second stage analysis. This second stage will employ a method developed by the UN-FAO. Changes in aggregate consumption of food commodities in different world regions from the CGE results will be used to calculate changes in average daily caloric intake in each region. The means of estimated distributions of daily caloric intake within each region will then be shifted commensurately, and changes in the proportions of each regions' population that fall to the left of the level of minimum caloric needs will be calculated. The use of CGE modeling for this analysis is especially attractive, as it will not only allows us to discern long-run effects without being distracted by short-run noise, but also allows us to thoroughly consider the growing general equilibrium entanglements between agricultural and energy markets.

This project's results should be of keen interest to policy makers, as they debate the merits of maintaining, extending, or eliminating the RFS. In addition to the food insecurity effects of the RFSs, the relatively high level of disaggregation in the agricultural sectors of the model will help policy makers and industry participants consider the effects of the mandates on various stakeholders (i.e., crop producers, livestock producers, consumers). NGOs should obviously be keenly interested in these results.

2 Methods

This paper employs an existing static computable general equilibrium (CGE) model of world trade. The model uses the Global Trade Analysis Project (GTAP) database, and employs a high level of disaggregation in the agricultural sectors relative to other large-scale CGE models. The model currently features extensions of the GTAP data which allow inclusion of grain, switchgrass, and corn stover-based ethanol production sectors. Changes in equilibrium levels of market variables and land use are determined for alternative scenarios, and food insecurity implications stem from a second stage analysis. This second stage employs a method developed by the UN-FAO. Changes in aggregate consumption of food commodities in different world regions from the CGE results will be used to calculate changes in average daily caloric intake in each region. The means of estimated distributions of daily caloric intake within each region will then be shifted commensurately, and changes in the proportions of each regions' population that fall to the left of the level of minimum caloric needs will be calculated.

2.1 Computable General Equilibrium (CGE) Model

We use a static comparative, multi-region, computable general equilibrium (CGE) trade model, based on Global Trade Analysis Project (GTAP) data. This model is described in (Bryant and Campiche, 2009). Model structure is similar to that of McDonald et al. (2005) and McDonald et al. (2006), but with more detailed representations of agricultural and biofuels-related activities. In this model, the primary factors of production are fully mobile across production activities, and the calculated equilibria are therefore long-run, and would be achieved after (potentially lengthy) periods of adjustment to technology and policy shocks.

This model facilitates analysis of the general equilibrium effects of biofuels policy. Partial equilibrium methods are certainly helpful for analyzing the effects of marginal increases in biofuels production on agricultural markets and trade. However such methods are less appropriate for considering other very interesting questions, such as the effects of very large changes from the status quo, the likely effects of new technologies for which no historical data exist, and the increasing influence of biofuels production on fossil energy market equilibria. Computable general equilibrium methods can overcome these limitations.

Interesting model features relate to biofuels production. The GTAP database does not contain information on biofuels production, and data from other sources, including USDA reports, and agronomic and engineering studies are used to calibrate and incorporate production sectors related to biofuels. New production sectors relate to feedstock production and production of biofuels themselves. Additionally, the existing petroleum and coal products sector is modified to reflect the incorporation of biofuels into the energy products distribution stream. Each of these enhancements is now described in turn.

A switchgrass production sector is added to the model, as switchgrass is a leading candidate cellulosic ethanol feedstock. Switchgrass is a summer perennial grass that is native to North America and is a dominant species of the remnant tall grass prairies in the United States. Switchgrass is resistant to many pests and plant diseases and has the potential to produce high yields with low fertilizer application rates. Switchgrass can be grown on marginal land with fairly moderate inputs and can also protect the soil from erosion problems (Duffy and Nanhou, 2002). The two main types of switchgrass are upland types (grows to 5 or 6 feet tall) and lowland types (grows to 12 feet tall). Switchgrass planting and harvesting is very similar to other hay crops and the same machinery can be used for harvesting. When switchgrass is produced for biomass, it can be cut once or twice a year. Switchgrass is currently grown as a forage crop on limited acreage in the Conservation Reserve Program (CRP), and on various test plots throughout the United States.

Adding a dedicated switchgrass sector follows the approach taken by McDonald et al. (2006), and contrasts with the approach of Raneses et al. (1998) who considered switchgrass an output of an existing "other hay" sector. As in McFarland et al. (2004), we calibrate the production technology for this sector using cost share and total cost information. Following McDonald et al. (2006), cost shares for the inputs into switchgrass production are set to levels similar to those of similar crops in the GTAP database. The total cost of switchgrass production in the base year is based on a broad literature review (Duffy, 2008; Duffy and Nanhou, 2002; Khanna and Chapman, 2001; Mapemba et al., 2007; Perrin et al., 2003, 2008; Turhollow, 2000; Vogel, 2007; Walsh et al., 2003; Ugarte et al., 2003). Individual estimates from these sources were adjusted based on their varying assumptions, and a average price of approximately $65 per ton is used in calibrating this sector. This cost is exclusive of transportation costs, which are borne by the consumer. In contrast to standard practice in CGE model calibration, we use actual price per ton for switchgrass, and model quantities are therefore measured in standard physical units (c.f., physical units that are implied by a base year price of unity).

Corn stover is a byproduct of corn grain production and consists of the stalk, leaf, husk, and cob remaining in the field after the corn grain harvest. The main component of corn stover is cellulose. Corn stover composition and moisture content varies due to several factors such as region, soil type, weather, corn variety, and harvesting methods (Aden et al., 2002). Half of the corn crop yield by weight is corn stover, but it is generally left in the field after harvest. A portion of the stover can be collected and used as a biomass source for cellulosic ethanol production, but a certain percentage must be left on the ground to avoid soil erosion. Less than 5% of corn stover production is generally used presently (Hettenhaus and Wooley, 2000).

Given that large quantities of corn stover are currently produced, yet little is utilized, they are likely the lowest cost biomass source as cellulosic ethanol production begins (Gallagher et al., 2003). Consideration of corn stover is therefore critical to ensuring that an unrealistic level of dedicated energy crop production is not provoked by increases in cellulosic ethanol production. We incorporate stover as a fixed proportions joint product of cereal grain production (Figure 1). Costs for producing corn stover are therefore not separately modeled, but

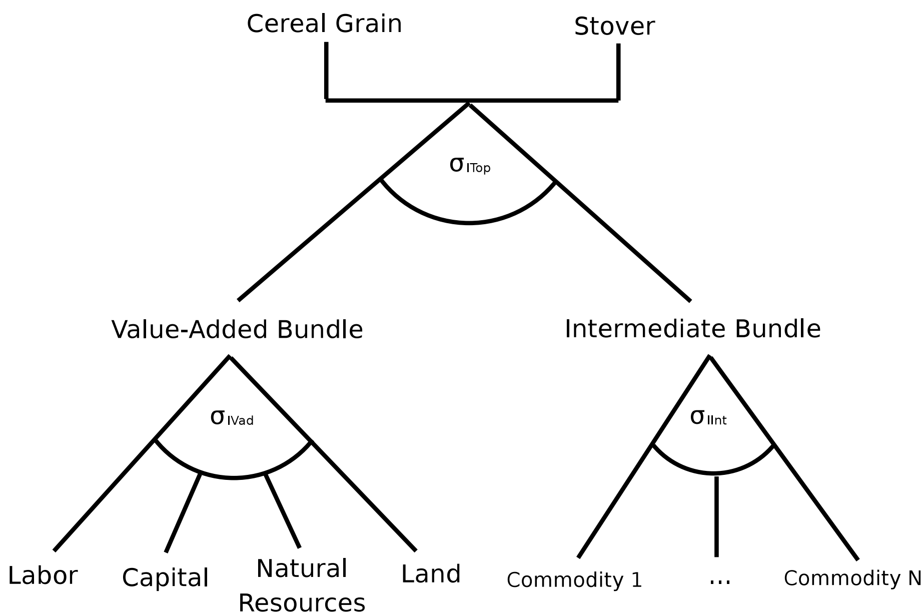

Figure 1: Joint Production of Coarse Grains and Stover

are instead shared with the cereal grains production activity. Collection and transportation costs for stover in this model are borne by the consumer.

A portion of the corn stover can be collected and used as a biomass source for cellulosic ethanol production. The amount that can be removed varies by region, soil conditions, and harvest activities. Corn stover is very important in preserving the organic matter and nutrients in the soil following corn grain harvesting and preventing soil erosion. It is difficult to establish a corn stover removal rate that is ideal for all regions due to variations in soil and weather conditions. Additionally, stover collection is restricted by several constraints relating to available collection technologies. For the purposes of this model, we assume a stover collection rate of 30%, which is consistent with available collection technology and is believed sustainable from an erosion standpoint.

Two ethanol production sectors are incorporated into the model, reflecting two possible feedstocks: cereal grains and biomass. Fuel ethanol production from grain feedstocks is a mature technology, and numerous estimates of production costs and their structure are available. Calibration of the production function is again accomplished by calibrating cost shares and total cost to available cost studies, as described above for switchgrass production. Numerous such studies were reviewed (Tiffany et al., 2008; Environmental Protection Agency, 2007; Eidman, 2007; Burnes et al., 2005; Shapouri and Gallagher, 2005; Wallace et al., 2005; Tiffany and Eidman, 2003; McAloon et al., 2000), and the individual unit cost estimates were adjusted to reflect a 2004 corn price (corresponding

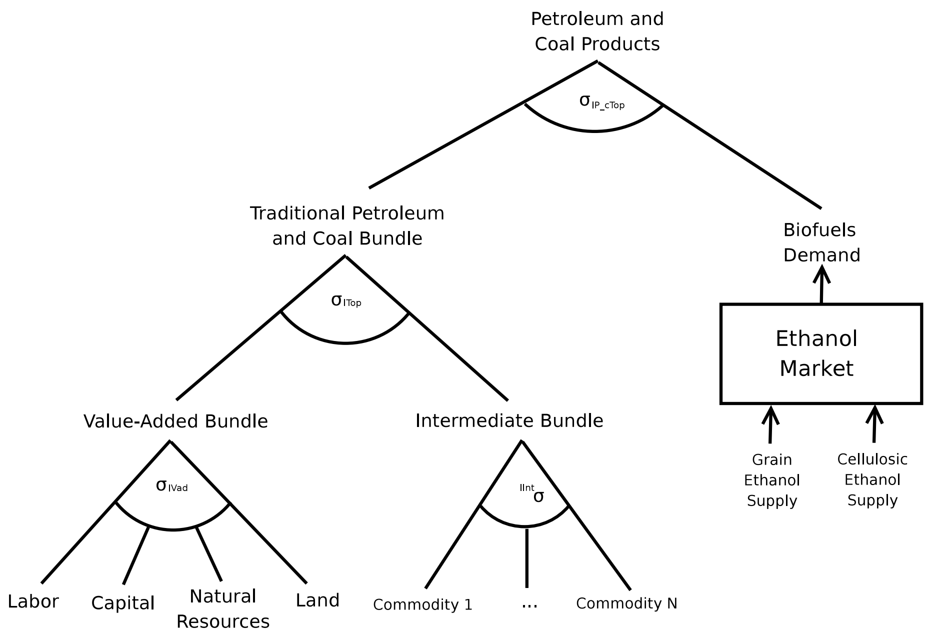

Figure 2: Petroleum and Coal Products Sector

to our base year). The average adjusted unit cost estimate of about \$1.21 is employed in calibration. Cost shares for individual inputs were averaged over available studies as well, and those averages were used for calibration.

So-called cellulosic ethanol is widely viewed as a promising avenue for development of sustainable, domestically produced liquid fuel. Cellulosic ethanol is produced by converting cellulose from plants into sugars which can then be fermented and distilled using standard technology. Enzymatic hydrolysis is the technology being most actively pursued for cellulosic conversion, and this is the technology against which we calibrate cellulosic ethanol production sectors. This technology is much less mature than that for grain-based ethanol, and production on large commercial scales has yet to commence. Cost estimates therefore reflect a fair amount of uncertainty. Available cost studies vary widely in their assumptions, particularly regarding production scale, feedstock costs, and enzyme costs.

We incorporate both corn stover and switchgrass as biomass feedstocks for cellulosic ethanol production. All available cost estimates concern producing cellulosic ethanol from switchgrass (Aden et al., 2002; McAloon et al., 2000; Wallace et al., 2005; Wooley et al., 1999), and these cost data are used for calibration. The different cost estimates are normalized to reflect identical biomass costs, and to reflect the cost of biomass collection and transportation. The resulting average normalized estimate of total unit cost of \$2.08 is used in the calibration. Individual costs from the studies reviewed were categorized and aggregated as appropriate, and the these categorized costs were mapped to the primary factors and commodities employed in the model. As with the biomass and grain ethanol production sectors, actual unit costs are used as the base year price rather than unity, and the corresponding output quantity variables are therefore measured in standard physical units.

All biofuels are consumed by a petroleum and coal products production sector. This arrangement is similar to Reilly and Paltsev (2007), who assume that the output of their "bio-oil" sector is a perfect substitute for refined oil products. The arrangement is also somewhat similar to McDonald et al. (2006), who consider switchgrass as a substitute for crude oil in the production of refined petroleum products. More generally, the use of biofuels as an input into production of petroleum products is consistent with the nature of actual biofuel marketing, which typically involves the distribution of blends of biofuels and traditional petroleum-based fuels. The petroleum and coal products production sector is depicted in Figure 2. Traditional petroleum and coal products are produced in a nested sub-tree structured like all other commodity production functions in the model. Biofuels and the composite traditional coal and petroleum-based products good are used in the production of the new, more broadly defined petroleum and coal products commodity. The top nest is calibrated using the value of production of the traditional coal and petroleum products, the quantity of fuel ethanol produced in 2004, and the 2004 grain ethanol cost of production of about \$1.21. A moderately high degree of substitution is specified for this top nest. Note that cellulosic ethanol production is not used in the calibration as no cellulosic ethanol was produced or consumed in 2004. Cellulosic ethanol is instead incorporated as a latent technology that becomes active under appropriate market or policy conditions.

Currently in the model, ethanol is produced using either grain or biomass. The resulting ethanol is assumed to be homogeneous for purposes of use, but we do not restrict ethanol of different types to have a single price. This is accomplished by requiring the ethanol purchaser to purchase ethanol at a quantity-weighted price, and allowing a cellulosic ethanol to collect a price premium above grain ethanol if a cellulosic mandate is in place. This scheme is described by several equations and complementarity relationships in the model. The average cost of ethanol produced by both means is given by

$$P_{ave} = P_{conv}\left(\frac{Q_{conv}}{Q_{conv}+Q_{adv}}\right) + P_{adv}\left(\frac{Q_{adv}}{Q_{conv}+Q_{adv}}\right), \tag{1}$$

where *conv* currently corresponds to grain-based ethanol and *adv* currently corresponds to cellulosic ethanol. The price realized by blenders after the volumetric ethanol excise tax credit (VEETC) and supplemental cellulosic credits is

$$P_{final} = P_{ave} - VEETC_{conv}\left(\frac{Q_{conv}}{Q_{conv}+Q_{adv}}\right) + VEETC_{adv}\left(\frac{Q_{adv}}{Q_{conv}+Q_{adv}}\right). \tag{2}$$

The prices of individual fuels are relative to a base price

$$P_{conv} = P_{base} \tag{3}$$

and

$$P_{adv} = P_{base} + \lambda_{adv} \tag{4}$$

where $\lambda_{adv} \geq 0$ is a price premium for advanced biofuels. The market excess supply of ethanol is

$$Q_{conv} + Q_{adv} - Q_{demanded} \geq 0 \perp P_{base} \geq 0. \tag{5}$$

Here, the $\perp$ symbol denotes a complementarity relationship, wherein exactly one of either the excess supply or P_{base} is exactly zero, and the other is strictly greater than zero. Finally, an Advanced RFS can be imposed, allowing a positive price premium for biofuels:

$$Q_{adv} - RFS_{adv} \geq 0 \perp \lambda_{adv}. \tag{6}$$

Quantities of biofuels are modeled in gallons (not abstract units such that base year prices equal unity), so imposition of production mandates is straightforward.

Currently, no advanced (as defined in RFS2) biofuels other than cellulosic ethanol are incorporated into the model, so we do not currently separately model the "Advanced" RFS and the "Cellulosic" RFS. The total RFS (total biofuels of any kind) is imposed by requiring a minimum level of use of the biofuels bundle by the top nest of the petroleum and coal products activity.

2.2 Estimation of Food Insecurity

We adopt the UN Food and Agriculture Organization (FAO) method for estimating changes in the numbers of food insecure people (Naiken, 2002) as aggregate consumption of food commodities changes. The FAO measure endeavors to capture those whose food consumption level is insufficient for body weight maintenance and work performance, focusing on the phenomenon of hunger rather than poor nutrition. The FAO measure of food insecurity is based on a probability distribution framework. Given the distribution of dietary energy consumption $f(x)$, the percentage of undernourished people is estimated as the proportion of population below the minimum per capita dietary energy requirement r_L. This arrangement is illustrated in Figure 3. r_L is derived by aggregating the estimated gender and age-specific minimum dietary energy requirements, using the relative proportions of a population in the corresponding sex-age group as weights. The estimates are calculated on a country-by-country basis and are reported periodically by FAO.

The distribution $f(x)$ is estimated based on household surveys, which collect data on the quantities of food product consumed by individuals in a representative sample of households in the population. However, the methodology and concepts applied in the surveys are not sufficiently precise to provide an accurate

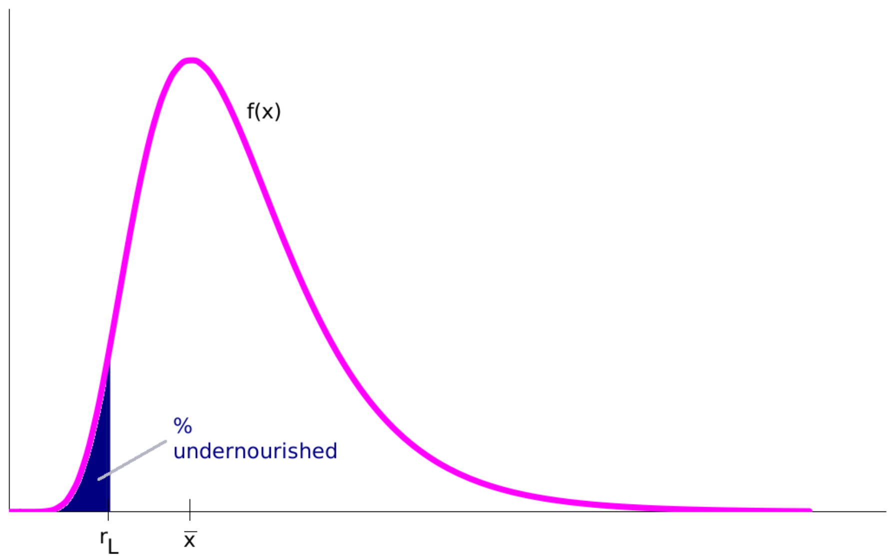

Figure 3: FAO Method of Calculating the Number of Undernourished People in a Region.

and reliable estimate of the distribution, and FAO therefore employs a theoretical distribution. The frequency distributions suggested by the food survey data are generally unimodal, and FAO considered a specific group of appropriate distributions.

FAO initially employed the Beta distribution, as it enabled fixing the lower and upper limits of the range as determined by the physiological lower and upper limits of intake in individuals. However, researchers found this distribution was appropriate only when dealing with the true intake of individuals. In most of the surveys, the data refer to the food available to, or acquired by, the household and thus include household wastage, food fed to pets, etc. Since 1987, FAO has instead employed the two-parameter log-normal distribution. The short lower tail and long upper tail better reflect the richer and more affluent households, who are more likely to have wastage, food fed to pets, etc.

The log-normal distribution can be specified by two parameters, the coefficient of variations $CV(x)$, and the mean $(\overline{x})$. Given these two parameters, the mean and variance of the corresponding normal distribution can be determined as

$$\sigma^2 = ln\left(CV^2(x) + 1\right)$$

and

$$\mu = \frac{ln(\overline{x}) - \sigma^2}{2}.$$

The $CV(x)$ is estimated as

$$CV(x) = \sqrt{CV^2(x|v) + CV^2(x|r)}$$

where $CV(x|v)$ is variation owing to household per capita income, v, and $CV(x|r)$ is variation due to the energy requirement r. A detailed procedure of estimation is documented in (Naiken, 2002). Because the inequality of income distribution for a number of developing countries varied little over last three decades, and the inequality in the distribution of household per capita food consumption is much smaller than the inequality in the distribution of household income, and $CV(x)$ is assumed to be constant.

The mean $\overline{x}$ represented by the per capita dietary energy supply refers to the energy available for human consumption, expressed in kilo-calories (kcal) per person. It is derived from the food balance sheets (FBS) compiled every year by FAO on the basis of data on the production and trade of food commodities. The total dietary energy supply is obtained by aggregating the food component of all commodities after being converted into energy values.

Energy requirements are different for different individuals. The most influential factors are age, sex, body weight, and activity level. The r_L for a country is derived by aggregating the minimum sex-age-specific energy requirement with information on the composition of the population.

The sex-age-specific energy requirement is derived in two procedures. For adults and adolescents, the energy requirements are calculated with the basal metabolic rate (BMR). For children below age ten, the energy requirements are expressed as fixed amounts of energy per kilogram of body weights. The lower limits of the requirements for each sex-age group were derived with the lowest acceptable body weight and lowest acceptable activity allowance. r_L is around 2,000 kcal per day for each country, and is updated by FAO periodically as the composition of population changes over time.

FAO provides caloric intake distributions for a much larger number of countries/regions than are featured in the CGE model. To estimate the daily calorie intake distribution for each of nine aggregate regions that correspond to the regions of the CGE model, we adopted a two-step Monte Carlo simulation method. First we randomly draw a country i within the region with probabilities equal to the population weights. We then randomly draw a number from the specific country's distribution $f_i(x)$. We employ 65,500 trials for each aggregate region to estimate its empirical aggregate caloric intake distribution $f(x)$. While we take care to accommodate the possibility of complex aggregate caloric intake distributions, all nine of the simulated aggregate distributions appeared unimodal with an approximate log-normal shape. Within each region, the per capita dietary energy supply for each country was aggregated by the population weights, using the 2004 Food Balance Sheets. Per capita dietary energy supply from each food group in our model is also aggregated in the same way.

Similarly, the lowest energy requirement level r_L is aggregated with population weights of the countries within the specific region. With the daily calorie intake distribution $f(x)$ and the lowest energy requirement level (r_L) for each region, we can update the mean $\overline{x}$ corresponding to the results from the CGE model, and calculate the proportion of undernourished people within each region for different scenarios.

3 Scenarios to be Analyzed

We use a base solution corresponding to the 2004 base year equilibrium. Counterfactual scenarios will correspond to the imposition of a total RFS of 31 billion gallons, and a cellulosic RFS of 16 billion gallons. Two alternative scenarios will be considered. In the first scenario, we calculate an equilibrium with with the RFSs imposed and where cellulosic ethanol can be produced at current full costs. In the second scenario, we again again impose the RFSs, but we assume that input-intensive technical change results in a reduction of 55% in the cost of the enzymes required to produce a fixed quantity of cellulosic ethanol.

4 Preliminary Results

As of this writing, preliminary results based on an earlier version of the model and an modest RFS-like mandated ethanol production increase are available. The preliminary results described below do not reflect the full RFS scenario described in the previous section. Instead, these preliminary results are based on a mandated increase in total ethanol production of 5 billion gallons. A base model solution reflects production of 10 billion gallons of ethanol. Two scenarios are considered. In the first scenario, we calculate an equilibrium with a constraint that at least 15 billion gallons of ethanol are required, and cellulosic ethanol is produced at current full costs. In the second scenario, we again require at least 15 billion gallons of ethanol production, but we assume that input-intensive technical change results in a reduction of 55% in the cost of the enzymes required to produce a fixed quantity of cellulosic ethanol.

Under the expensive enzyme scenario, only about 1.25 billion gallons of the total 15 billion gallons is produced using cellulosic feestocks (Figure 4), and this is essentially all stover. Stover prices remain below the cost of switchgrass production in both scenarios. It is therefore the preferred feedstock, and the switchgrass production activity is operated at zero intensity in both scenarios. With a 55% percent reduction in enzyme costs, almost 4 billion gallons of ethanol is produced using stover. A likely predominance of stover over switchgrass as a cellulosic ethanol feedstock is consistent with the findings of Milbrandt (2005) and U.S. Department of Agriculture (2007).

Relatively modest changes in long-run equilibrium prices for food commodities under the increased ethanol production scenarios result in relatively modest changes in average per capita caloric consumption (Table 1). The largest changes in caloric intake occur in the U.S., where the ethanol production occurs. The U.S. population also consumes relatively large quantities of cereal grains indirectly via livestock production relative to other world regions, and increased grain prices thus lead to lower consumption of high-calorie meat products. Higher world prices for commodities influence other regions' caloric intake as well, with regions' reliance on ag imports heavily influencing relative results. Brazil, a major exporter of ag commodities enjoys higher income following an increase in U.S. ethanol production, and therefore increases consumption of food

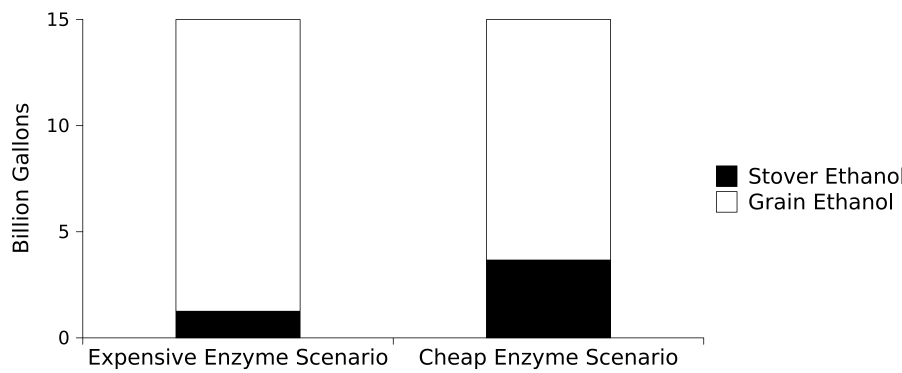

Figure 4: U.S. Production of Grain and Cellulosic Ethanol Under a 15 Billion Gallon Mandate in Alternative Cellulosic Cost Scenarios.

Table 1: Changes in Mean per Capita Daily Caloric Intake

	Expensive Enzymes	Cheap Enzymes
USA	-7.12	-3.88
Brazil	0.13	0.15
China	-0.75	-0.69
India	-0.04	-0.02
Other Far East	-1.00	-0.43
Western Europe	-0.35	-0.24
Eastern Europe and FSU	0.02	0.02
Central and South America	-1.05	-0.42
Rest of the World	-0.74	-0.57

commodities. Many Far East countries other than China (e.g., Japan), by contrast, rely heavily on agricultural imports and consume fewer calories as food prices increase. In all regions with reduced caloric intake, the reductions are smaller under the cheap enzyme scenario, wherein less food (i.e., grain) is used to fuel increased ethanol production.

Changes in the percentage of the population in each region that is food insecure are determined by the interaction of the magnitude of the shift in mean caloric intake described above and by the percentage of the each region's population that was food insecure under the base scenario. While the largest declines in caloric intake were in the U.S., only a very small proportion of the U.S. population is food insecure, with a large majority of consumers enjoying a significant daily caloric surplus. Thus shifting the distribution of caloric intake, as described in subsection 2.2, only shifts a very small area to the left of the minimum caloric need (Table 2). In short, Americans can easily afford to eat less.

Changes in other regions vary. Among regions with significant food insecure

Table 2: Percentages of Populations that are Food Insecure

	Base	Expensive Enzymes	Cheap Enzymes
USA	0.134%	0.142%	0.137%
Brazil	8.933%	8.928%	8.928%
China	11.557%	11.582%	11.579%
India	25.733%	25.736%	25.734%
Other Far East	8.762%	8.794%	8.774%
Western Europe	0.354%	0.356%	0.354%
Eastern Europe and FSU	7.177%	7.176%	7.176%
Central and South America	11.160%	11.195%	11.171%
Rest of the World	24.611%	24.643%	24.635%

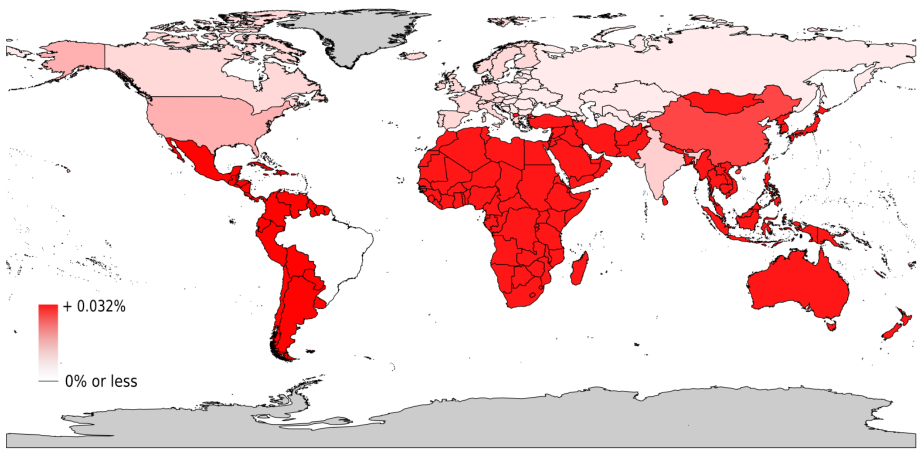

Figure 5: Changes in Percent of Population that is Food Insecure as Ethanol Production Increases, Full-cost Enzyme Cost Scenario.

population (i.e., regions other than the U.S. and Western Europe), the largest increases in the percentages of food insecure people occur in the Other Far East, Central and South America, and Rest of the World regions. The changes in these percentages for the two scenarios relative to the base solution are depicted graphically in Figures 5 and 6. Brazil (a significant food exporter) and regions that minimally rely on food imports fair better.

The numbers of people in each region multiplied by the percentage changes reported in Table 2 imply the absolute numbers of people that become (or cease to be) food insecure. These absolute numbers are depicted in Table 3. Almost all of the increase in food insecure people occurs in the Far East (China and Other Far East regions), Central and South America (excluding Brazil), and the Africa (comprises a large portion of the Rest of the World region). Overall, however, the net change in the number of food insecure people worldwide is relatively modest, at about 1.2 and 0.8 million people in the expensive and cheap enzyme

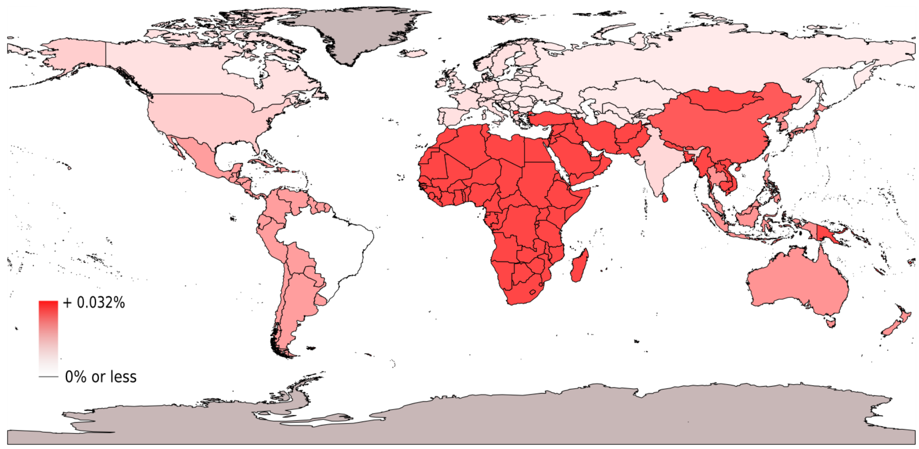

Figure 6: Changes in Percent of Population that is Food Insecure as Ethanol Production Increases, Lower Cost Enzyme Cost Scenario.

Table 3: Changes in Numbers of Food Insecure People (millions)

	Expensive Enzymes	Cheap Enzymes
USA	0.023	0.009
Brazil	-0.008	-0.008
China	0.316	0.276
India	0.032	0.016
Other Far East	0.184	0.070
Western Europe	0.006	0.000
Eastern Europe and FSU	-0.006	-0.006
Central and South America	0.122	0.037
Rest of the World	0.514	0.391
Total	1.182	0.786

scenarios, respectively. This reflects minimal changes in food prices.

These preliminary results reflect only a 5 billion gallon per year increase in ethanol production, and it is certain that an increase of 20 billion gallons or so will have commensurately larger effects on world hunger.

4.1 Caveats

Most importantly, the results presented above are only preliminary, and do not reflect the full U.S. Renewable Fuel Standard, with individual requirements for total and cellulosic consumption. Several other caveats apply to this work. First, the calculated equilibria are long-run, and would occur after potentially lengthy adjustment periods. Short-run results may well be more painful in terms of food insecurity, as the agricultural economy gropes with the shock of increasing diversion of its output into fuel production. Second, the enzymatic hydrolysis of non-woody biomass reflected in our model is but one among many competing cellulosic feedstock-technology pairs, although this combination seems to have the most momentum. Third, the eventual extent of cost reductions for the enzymatic hydrolysis technology are clearly uncertain, and our assumption of a 55% reduction in enzyme costs merely reflects one possibility. Fourth, we are not accounting for improvements in coarse grain productivity, which would tend to overstate the net increase in food insecurity. We are using 2004 population numbers and FAO calorie distributions, which would tend to understate net increases in food insecurity. Finally, and perhaps most importantly, we are not presently accounting for increases in biofuel production in regions other than the U.S., and the RFS calls for much larger increases in ethanol production than the 5 billion gallons that we consider here. Larger increases in worldwide biofuel production would also tend to understate net increases in food insecurity.

5 Conclusions

Overall, we expect that large increases in U.S. ethanol production would result in moderate increases in worldwide food insecurity, after a (potentially lengthy) adjustment period. Significant improvements in cellulosic ethanol production technology would substantially reduce the magnitude of such changes, as increases in ethanol production could be fueled by previously unutilized ag wastes.

Increases in cellulosic ethanol production are likely to be fueled by ag waste rather than dedicated energy crops. Production of coarse grains is certain to increase as ethanol production increases, as both the grain and associated stover represent current and likely feedstocks for future ethanol production. Changes in food insecurity caused by increasing ethanol production would tend to be most painful in Africa, the Far East, and Central and South America (excluding Brazil), although such changes would likely be modest in the long run for moderate increases in ethanol production.

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