Land Use Implications of Biofuel Production in the Presence of Idled Cropland and Crop Yield Improvement: Analytical and Numerical General Equilibrium Analyses

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Introduction

The land use implication of biofuel production is a controversial issue. The early papers published in this area show that the US ethanol production could have extraordinary land use implications (e.g. Searchinger et al. 2008). However, the more recent publications in this field (e.g. Hertel, Tyner, and Birur 2010; Taheripour et al. 2010; Taheripour, Hertel, and Tyner, 2009; and Hertel et al., 2010) indicate that the land use implications of biofuels are smaller, but they are important and could alter the advantages of biofuels versus traditional fossil fuels. These papers emphasize on the market-mediated responses to biofuel programs and highlight the role of biofuel by-products in offsetting the adverse land use impacts of biofuel expansion. These analyses neglect the technological progress in crop production and they do not take into account that the existing unused croplands (such as existing cropland pasture in the US) can be used to satisfy a portion of demand for crops for biofuels.

On the other hand advocates of biofuel programs, according to some historical observations and projections, argue that crop yield improvement and technological progress could eliminate the land use consequences of biofuel mandates. In addition, they believe that biofuel mandates and yield improvement could encourage farmers to bring unused cropland (such as cropland pasture or retired lands) into crop production and hence these factors could significantly reduce the land use consequences of biofuel programs.

Objectives

This paper develops analytical and numerical general equilibrium models to investigate impacts of producing more biofuels on the allocation of land between its alternative uses (forest, crop, and livestock) in the absence and presence of yield growth.

Stylized Analytical General Equilibrium Model

Endowments: Land ($\bar{L}$), Labor ($\bar{B}$), Capital ($\bar{K}$), and Resources ($\bar{R}$) are exogenous endowments. The land owner could set aside a portion of land, L_H, for environmental benefits.

Industries and commodities:

- A representative industry which produces a generic crop (*C*) with the following production function; $C = C(\propto_C L_C, B_C, K_C)$, where $\propto_C$ represent productivity of land in crop industry,
- A representative industry which produces a generic forest product (*F*) with the following production function; $F = F(\propto_F L_F, B_F, K_F)$, where $\propto_F$ represent productivity of land in livestock industry,
- A representative industry which producers a generic livestock product (*M*) with the following production function; $M = M(\propto_M L_M, B_M, K_M)$, where $\propto_M$ represent productivity of land in forest industry,
- A representative industry which produces fossil fuels (*O*) using natural resources with the following production function; $O = O(B_O, K_O, R_O)$,
- An representative industry which produces ethanol (*E*) using the generic crop with the following production function; $E = E(C_E, B_E, K_E)$,
- An representative industry which produces other goods and services (*G*) with the following production function; $G = G(L_G, B_G, K_G)$,

All production functions are assumed to be constant return to sale.

A representative consumer:
A representative household is considered in the model. This household owns all resources and supplies them to the producers. This household buys commodities noted above from their producers. This household also keeps some lands for environmental benefits. The representative household has the following utility function:

$$U = U(C_H, F_H, M_H, O_H, E_H, G_H, L_H)$$

Main Results Obtained from Analytical Model:
Using the production functions, utility function, and market clearing conditions of this economy we showed that:

Case A - In the **absence** of yield improvement, when the area of **idled** land, L_H, is **fixed** a mandatory shock in ethanol production (ΔE) will lead to:

- A reduction in welfare ($\downarrow U$),
- An increase in land used for crop production ($\uparrow L_C$) and reductions in forest ($\downarrow L_F$) and pastureland ($\downarrow L_M$) ,
- The magnitude of $\Delta L_C < \frac{\Delta E}{\Omega}$, where Ω is the ethanol yield per unit of cropland before shock. This is due to:
    - Reduction in household demand for crop ($\downarrow C_H$) due to higher crop price,
    - And using more labor and capital in the production process of crop,
- The magnitude of ΔL_C depends on:
    - The Own and Cross Price Elasticities of demands for crop, forest, and livestock products and their Income elasticities,
    - Elasticities of substitution among land, labor and capital in the production functions of crop, forest, and livestock industries,
    - Relative productivities of land in crop, forest, and livestock industries.

Case B - In the **presence** of yield improvement (an increase in $\propto_C$), when the area of **idled** land, L_H, is **fixed** a mandatory shock in ethanol production (ΔE) will lead to:

- All changes noted in case A,
- However, yield improvement reduces the size of welfare loss and land use impacts compared to the case A.

Case C - In the **presence** of yield improvement, when the area of **idled** land, L_H, can **change** a mandatory shock in ethanol production (ΔE) will to:

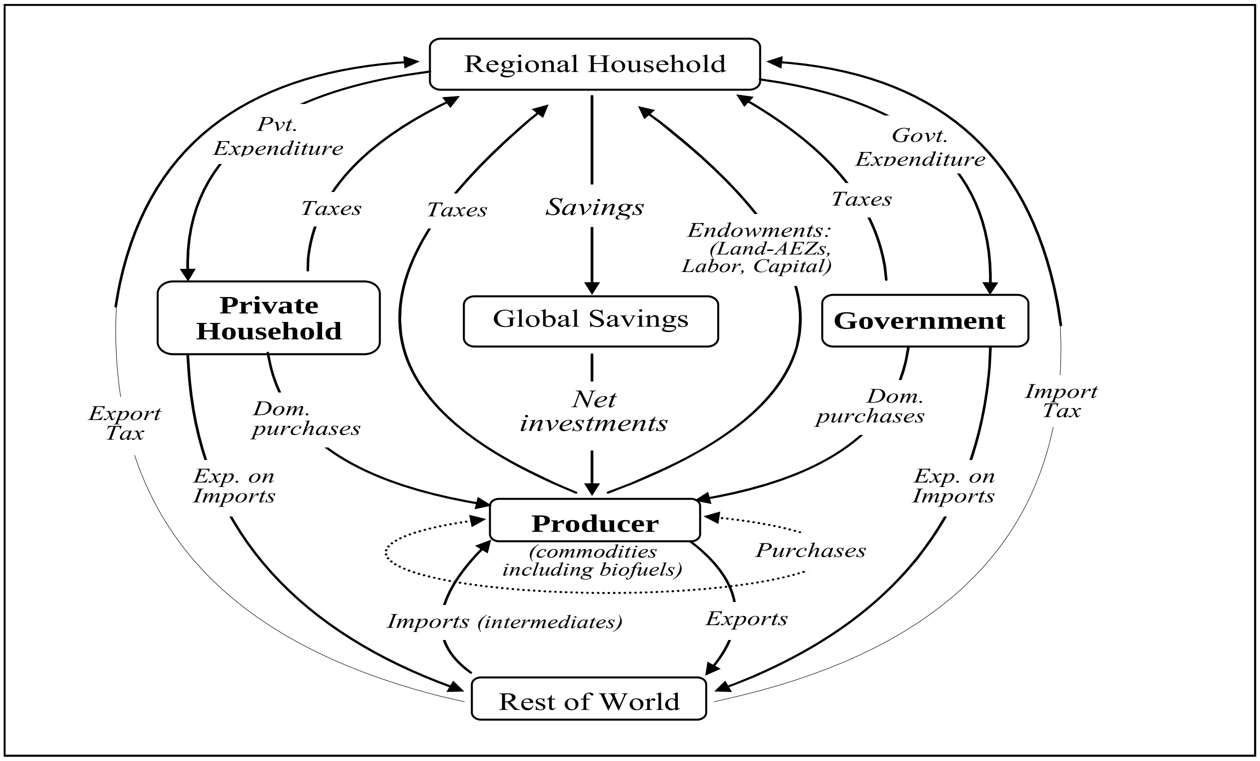
- All changes noted in case A,
- However, yield improvement reduces the size of welfare loss and land use impacts compare to the case B.

Numerical General Equilibrium Model

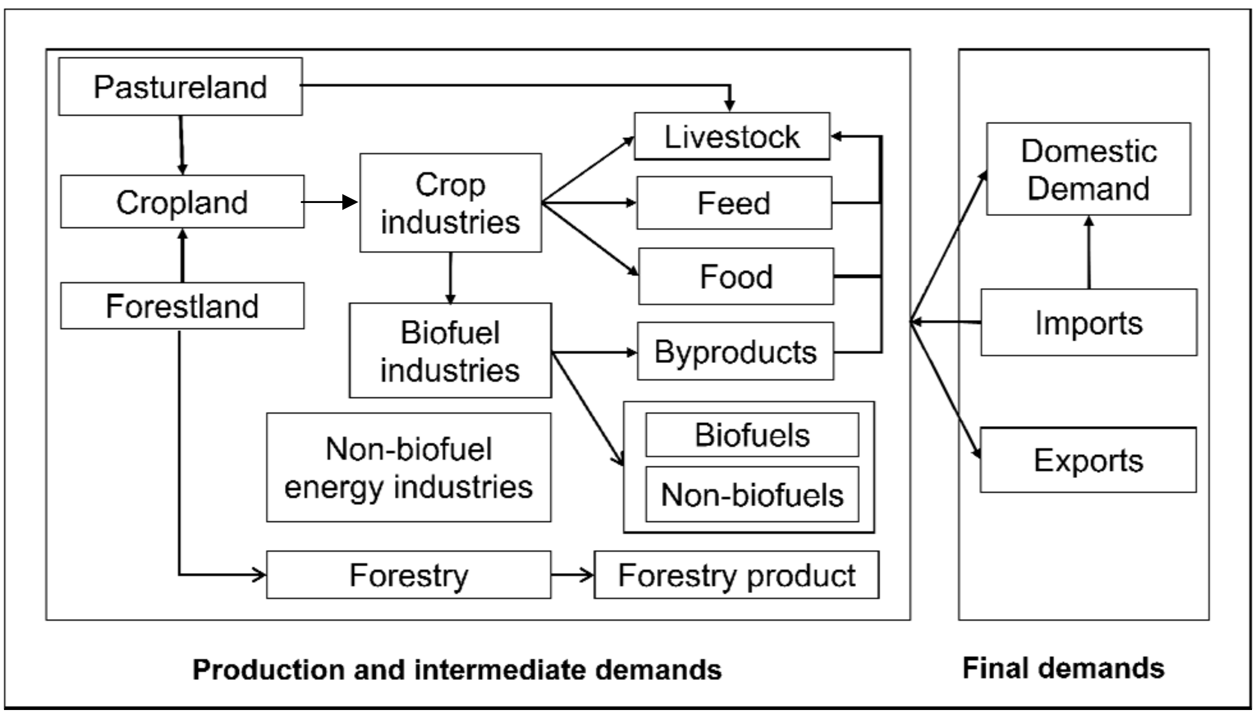
A Computational General Equilibrium Model is developed to investigate the global economic and land use impacts of the US ethanol program. The Model is a special version of the Global Trade Project Model (GTAP) developed at Purdue University. The latest version of the modified model for biofuel analyses is called GTAP-BIO-ADV. This model includes the following modifications in the standard GTAP model:

- The three major biofuels have been incorporated into the model: corn ethanol, sugarcane ethanol, and biodiesel.
- Cropland pasture in the US and Brazil and Conservation Reserve Program lands have been added to the model.
- The energy sector demand and supply elasticities have been re-estimated and calibrated to the 2006 reality. Current demand responses are more inelastic than previously.
- Corn ethanol co-product (DDGS) has been added to the model. The treatment of production, consumption, and trade of DDGS is significantly improved.
- The structure of the livestock sector has been modified to better reflect the functioning of this important sector.
- Corn yield response to higher corn prices has been estimated econometrically and included in the model.
- The method of treating the productivity of marginal cropland has been changed so that it is now based on the ratio of net primary productivity of new cropland to existing cropland in each country and AEZ.

An overview of the GTAP model



Major links associated with biofuels in GTAP-BIO-ADV



Outlines of simulations

A - Simulations out of 2001database with following major assumptions:

- No economic growth,
- No population growth,
- No technological progress,
- Yield intensification in respond to higher crop price with an elasticity of 0.25,
- Yield extensification of 0.66: Meaning that productivity of new cropland is 2/3 of productivity of existing cropland,
- No idled land in the model

B - Simulations out of 2001 with following major assumptions:

- No economic growth,
- No population growth,
- No technological progress,
- Yield intensification in respond to higher crop price with an elasticity of 0.25,
- Regional yield extensification obtained from a Terrestrial Ecosystem Model (TEM) based on the Net Primary Product of forest and pastureland compared with exiting cropland,
- In the presence of idled land (cropland pasture and CRP land).

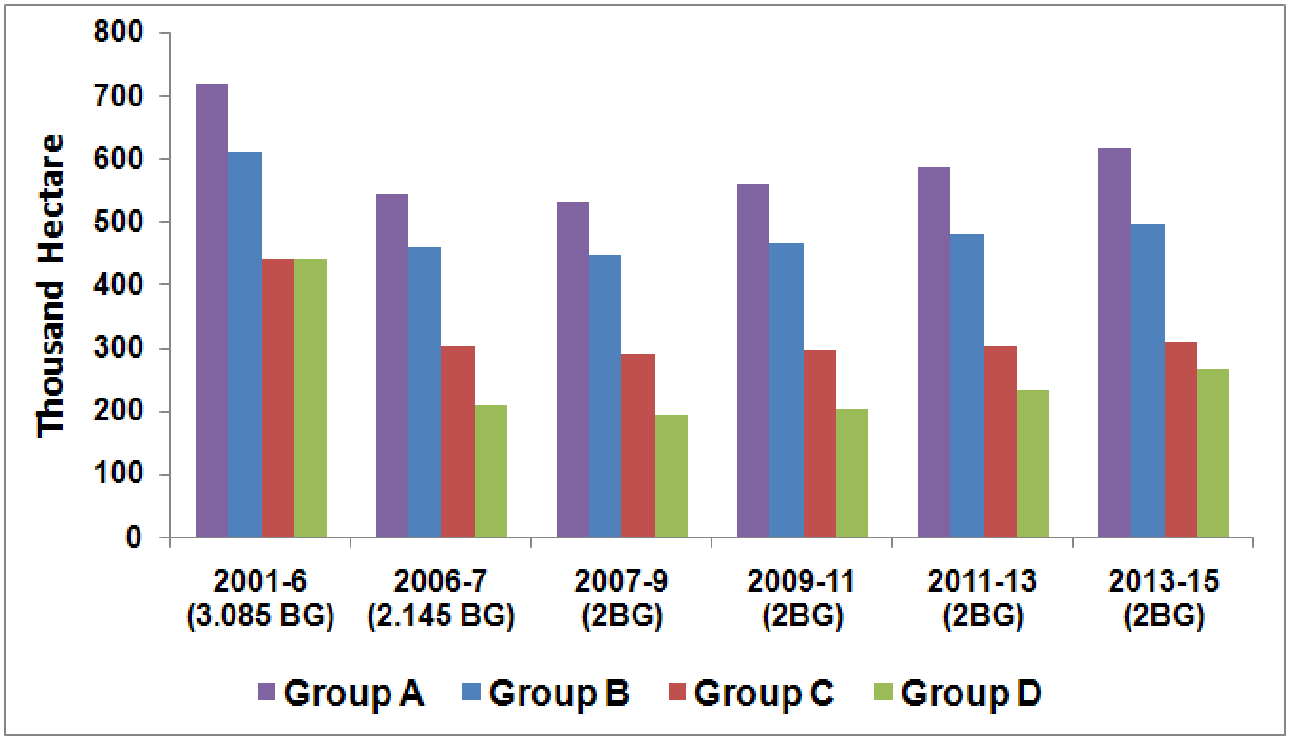
C - Simulations with updated baseline for 2001-2006 with the following assumptions:

- Transition from 2001 to 2006 world economy –key economic growth variables are included in the model up to 2006,
- No growth after 2006
- Yield intensification in respond to higher crop price with an elasticity of 0.25,
- Regional yield extensification obtained from a Terrestrial Ecosystem Model (TEM) based on the Net Primary Product of forest and pastureland compared with exiting cropland,
- In the presence of idled land (cropland pasture and CRP land).

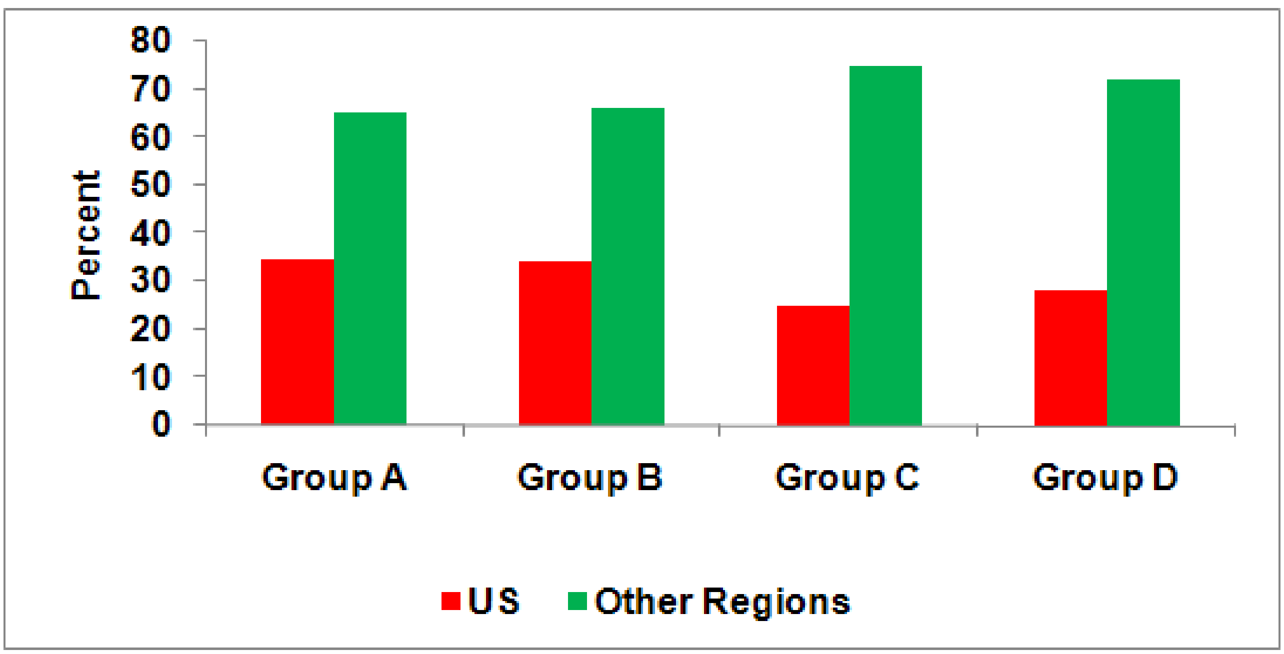
D - Simulations with crop yield and population growth for the time period of 2006-20015*with following assumptions*

- Transition from 2001 to 2006 world economy –key economic growth variables are included in the model up to 2006,
- Population will continue to grow following its past trend after 2006.
- Yield will grow at annual rate of 1% across all types of crops and regions after 2006No growth after 2006.
- Yield intensification in respond to higher crop price with an elasticity of 0.25,
- Regional yield extensification obtained from a Terrestrial Ecosystem Model (TEM) based on the Net Primary Product of forest and pastureland compared with exiting cropland,

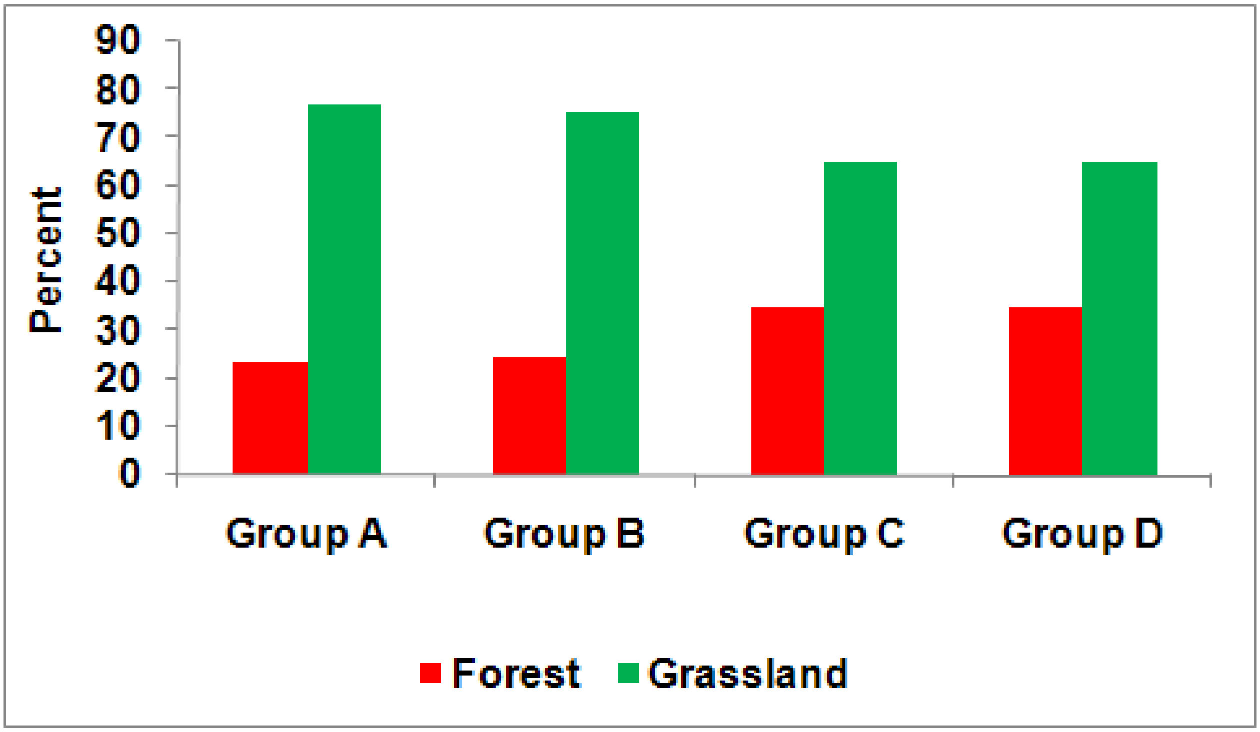
Some Simulation Results



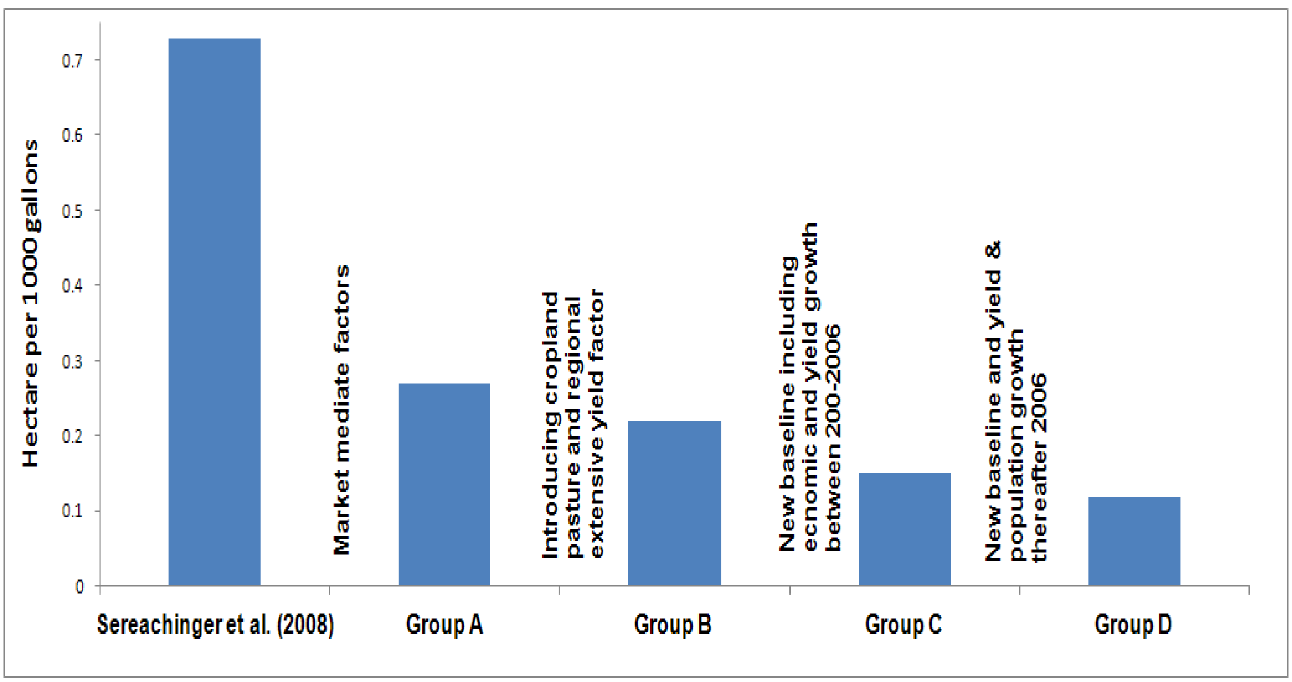
Land Requirements to Support US Ethanol Program under Alternative Scenarios



Distribution of Required Land for US Ethanol Program between US and Other Regions



Distribution of Required Land for US Ethanol Program between Forest and Grassland



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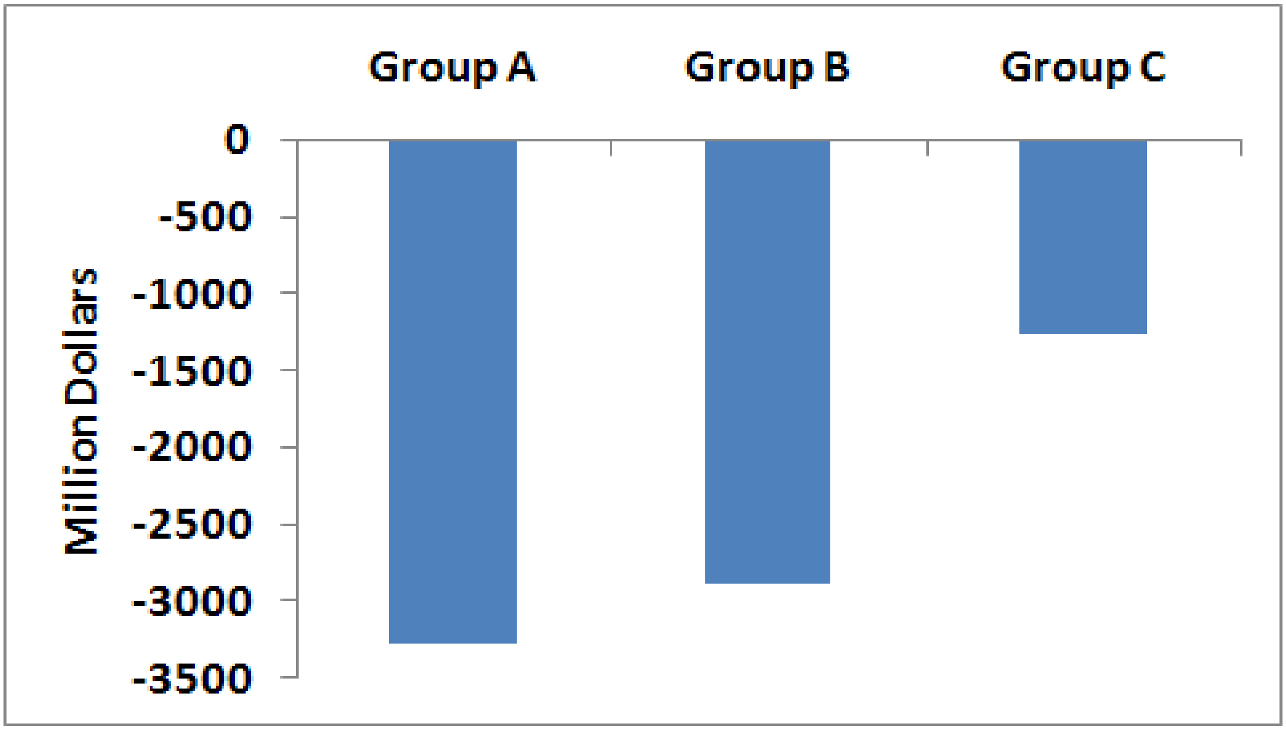
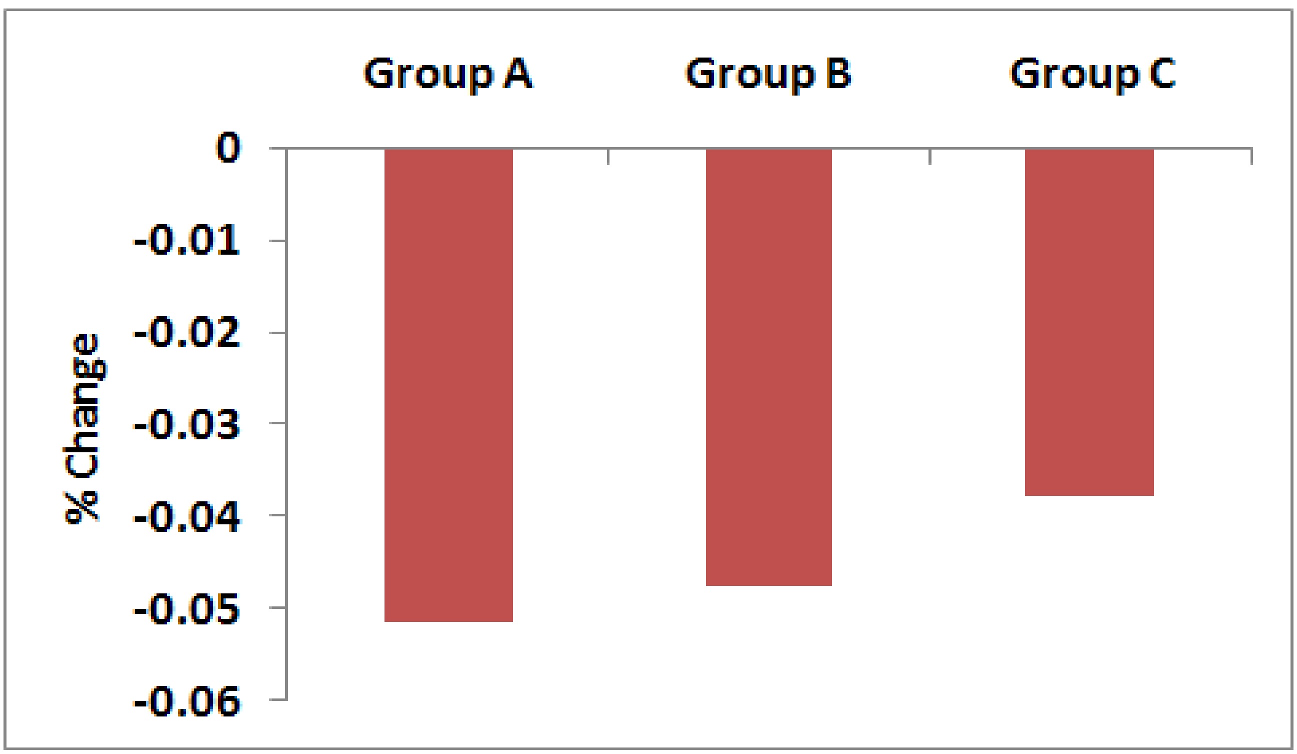


Changes in US Welfare due to an Increase in US Ethanol Production from 13 to 15 Billion Gallons under Alternative Scenarios



Changes in US Food Production due to an Increase in US Ethanol Production from 13 to 15 Billion Gallons under Alternative Scenarios

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