Welfare Impacts of Renewable Fuel Standard: Economic Efficiency vs. Rebound Effect

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1. Introduction

- The US Energy Independence and Security Act of 2007 (RFS2) defined mandatory targets to increase production of biofuels including ethanol,
- Several papers have examined welfare impacts of these mandates and argued that the US ethanol policy (RFS plus subsidy) reduces fuel prices, increases fuel consumption, and hence causes rebound effect (e.g. [1], [2], [3], and [4]).

Theoretical Background of Rebound Effect:

- The theory of rebound effect was first discussed by Jevons in 1868 when using a new steam engine led to a drop in coal price and an increase in coal consumption in UK [5].
- This theory argues that an increase in efficiency of an energy system could increase demand for energy. For example, higher fuel efficiency could increase miles driven by households which leads to an increase in fuel consumption [6].

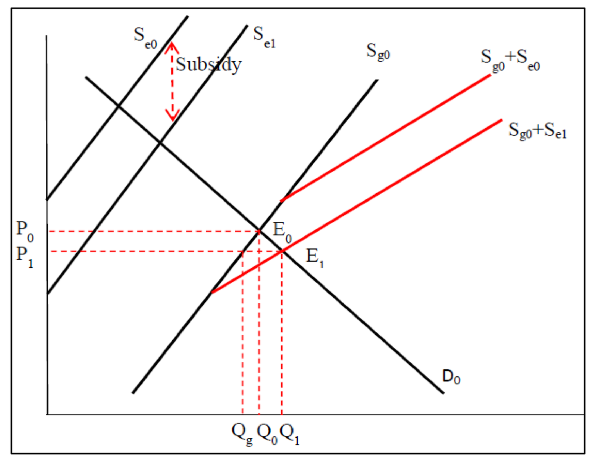
Research Questions

- The existing research which argues that the US ethanol mandate induces rebound effect has relied on *partial equilibrium (PE)* models.
- The partial equilibrium models only capture some economic impacts of biofuels mandates. Hence their conclusion on rebound effect could be misleading.
- To examine whether or not the US ethanol mandate could cause a rebound effect, we need a general equilibrium modeling framework to capture all possible economic impacts of this policy.

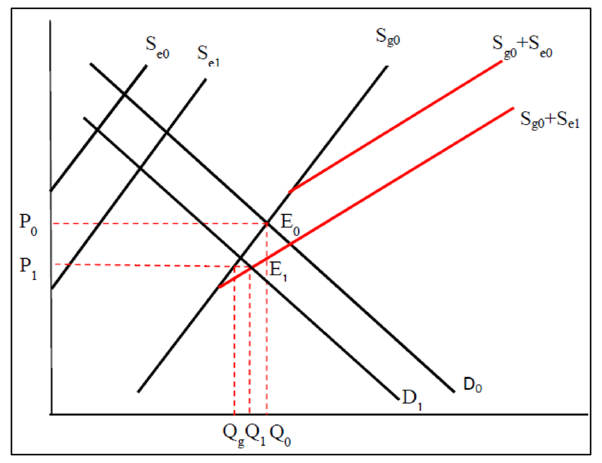
2. Objectives

- This paper develops analytical and numerical *General Equilibrium (GE)* models to examine the welfare impacts of alternative policies which can be used to expand production and consumption of biofuels.
- This analytical method decomposes the general equilibrium welfare impacts of these alternative policies into several components (including rebound effect) and shows how they interact and affect welfare. The analytical model also examines under what conditions the rebound effect can be observed.
- This paper uses the GTAP-BIO model developed by Taheripour, Tyner and Wang (2011) to quantify the welfare impacts of alternative biofuel policies and their corresponding rebound effects.

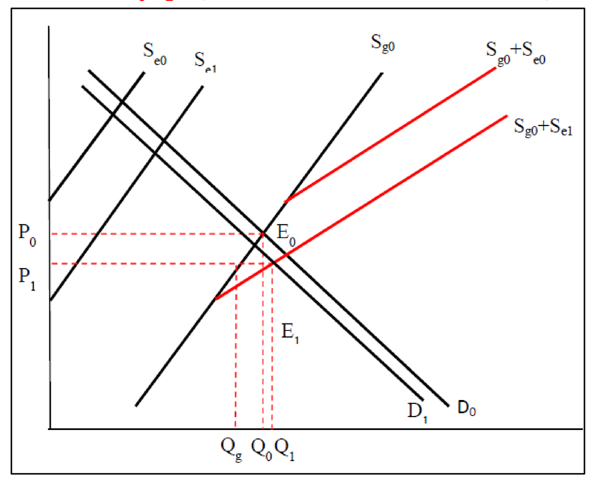
3. Rebound Effect in a PE Framework



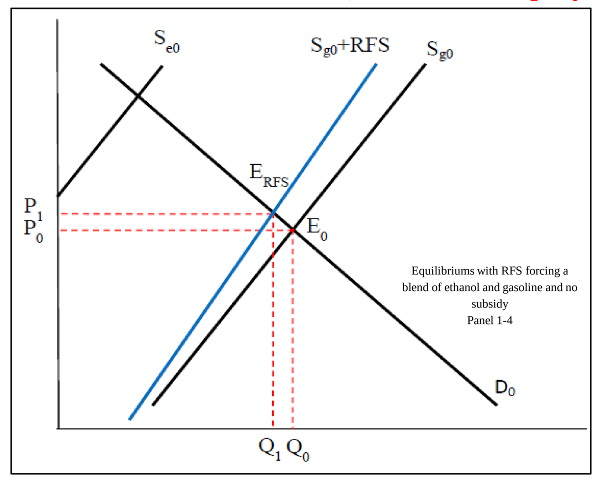
An increase in ethanol production due to ethanol subsidy could generate a rebound effect in a partial equilibrium model. Q_0Q_1 represents rebound effect in this figure.



If subsidy is financed by an income tax and a major change in income tax is required to finance the subsidy, then no rebound effect may be observed, $Q_1<Q_0$



If subsidy is financed by an income tax and a small changes in income tax is required to finance the subsidy, then a rebound effect can be observed, Q_0Q_1



If subsidy is not paid and only mandate is enforced then then no rebound effect can be observed, $Q_1<Q_0$

Why partial equilibrium models analyses could be misleading

- The partial equilibrium models ignore interactions between biofuel mandates and other distortionary commodity and income taxes.
- Biofuel mandates generate economic losses because they enforce the economy to use more expensive fuels. The partial equilibrium model usually ignores these costs.
- Biofuel subsidies could be financed by additional income or commodity taxes. This could generate more inefficiency.

4. A Stylized General Equilibrium Analytical Framework

- Consider and open economy which uses its endowments (land (R), labor (L), and capital (K)) to produce three commodities:
  - A dirty fuel (gasoline) represented by *X*,
  - A clean fuel (ethanol) represented by *E*,
  - Food represented by *Y*,
- The economy is open, it imports *X* and exports *Y*,
- Utility is increasing due to consumption of *X*, *E*, *Y*, and leisure$(\bar{L}-L)$but it suffers from induced emissions (*N*) due to fuel consumption,
- The government pays subsidy to increase production of ethanol. Income and commodity taxes and transfer payments are also in place,
- The household owns endowments and sells them to producers in return for income,
- The following optimization problem helps us to examine welfare impacts of ethanol policy:

$$\textbf{Max}\ \ u(C_X, C_E, C_Y, \bar{L}-L) - \emptyset(N)$$
$$\textbf{Subject to}: p_X C_X + p_E C_E + p_Y C_Y = (1-t_L)L + (1-t_R)r_R\bar{R} + (1-t_K)r_K\bar{K} + G$$

- The model is based on Taheripour et al. [7],
- Solving this optimization problem in combination with a comparative static method will show that an increase in tax credit $dS_E$for ethanol will generate the welfare impacts:

$$\frac{du}{\lambda ds_E} = \underbrace{-s_Y\frac{dO_Y}{ds_E}}_{\text{Primary food effect}} \underbrace{+t_m(O_X+x)\varepsilon_X\theta_X - s_E O_E\varepsilon_E\theta_E}_{\text{Primary Rebound Effect}}$$
$$\underbrace{-(1+\varepsilon_x)\frac{dp_X}{ds_E}x + p_X\frac{dx}{ds_E} + (1-\varepsilon_y)\frac{dp_Y}{ds_E}y + p_Y\frac{dy}{ds_E} + x\frac{dt_m}{ds_E}}_{\text{Primary Trade Effect}}$$
$$\underbrace{+M\left(\frac{dN_{LTR}}{ds_E}\right)}_{\text{Revenue Recycling Effect}} \underbrace{-\sum_{J=X,E,Y}\left(\tau t_L\left(-\frac{\partial L}{\partial p_J}\right)+\tau'(C_J)S_G\right)\frac{dp_J}{ds_E}}_{\text{Tax Interaction Effect}} \underbrace{+\tau t_L\varepsilon_{LQ}\left(\frac{L}{Q}\right)\left(\frac{dQ}{dt_N}-\frac{dG}{dt_N}\right)}_{\text{Non-Labor Income Effect}}.$$

This equation indicates:

- Welfare impact of ethanol subsidy is a function of shares, elasticities, and tax rates.
- Every component of this equation can be negative, positive, or zero.
- Their signs depend on magnitudes of demand and supply elasticities, tax rates, the efficiency of the tax system, and method of financing the ethanol tax credit.

5. General Equilibrium Rebound Effect

$$\frac{dC_X}{dC_E} = -\frac{1}{\varepsilon_{EX}}\frac{C_X}{C_E} - \left(\frac{\varepsilon_Y+1}{\varepsilon_{YE}}\right)\frac{C_Y}{C_E}\frac{p_Y}{p_X} + \left(\frac{\alpha_E}{\varepsilon_{IE}} - \frac{1+\varepsilon_E}{\varepsilon_E}\right)\frac{p_E}{p_X}$$

If $dC_X/dC_E \geq 0$:

- An increase in ethanol production does not reduce consumption of gasoline,
- In this case total consumption of fuel (C_X+C_E) goes up by (dC_E+dC_X: where $dC_X \geq 0$),
- Ethanol subsidy generates a *strong rebound effect*.

If $0 > dC_X/dC_E > -1$:

- An increase in ethanol production decreases consumption of gasoline with an amount less than the increase in ethanol production,
- In this case total consumption of fuel (C_X+C_E) goes up by (dC_E+dC_X: where $dC_X < 0$),
- Ethanol subsidy generates a *weak rebound effect*.

If $dC_X/dC_E \leq -1$:

- An increase in ethanol production decreases consumption of gasoline with an amount equal or larger than the increase in ethanol production,
- In this case total consumption of fuel (C_X+C_E) goes down or stays the same,
- Ethanol subsidy does not generate a rebound effect.

5. Numerical General Equilibrium Model: GTAP-BIO-AEZ

- A Computational General Equilibrium Model is used to investigate the global economic impacts of the US ethanol mandate under alternative scenarios.
- The Model is a special version of the Global Trade Project Model (GTAP) developed at Purdue University. It is based on the latest version of the modified model for biofuel analyses (GTAP-BIO-ADV developed by Tyner et al. [7]) and includes the following major extensions and improvements:
  - It uses version 7 of GTAP data base which depicts the world economy in 2004,
  - It covers production of consumption of first and second generation biofuels,
  - It handles production of co-products such as Dried Distillers Grains with Solubles (DDGS) and oilseeds meals.
  - Competition for land at Agro-Ecological Zones (AEZ) is included,
  - Demands for animal feedstocks including DDGS, oilseeds meals and traditional grains are included,
  - Adds greater flexibility in acreage switching among crops in the US in response to price changes,
  - Includes an endogenous yield adjustment for cropland pasture in response to changes in cropland pasture rent.
  - Unlike earlier versions, substitution among fuels is defined based on their energy content.
  - The ethanol subsidy can be financed using alternative policy taxes such as taxing blended fuel, income tax, or reduction of agricultural subsidies

6. Simulation Scenarios

- ***Experiment I:*** An increase in USA ethanol production from its 3.41 billion gallons in 2004 to 15 billion gallons mandated for 2015 using an incentive production subsidy per gallon of ethanol financed using a gasoline production tax.
- ***Experiment II:*** An increase in USA ethanol production from its 3.41 billion gallons in 2004 to 15 billion gallons mandated for 2015 using a production subsidy per gallon of ethanol financed using a gasoline production tax and by reduction of US agricultural subsidies to zero.
- ***Experiment III:*** An increase in USA ethanol production from its 3.41 billion gallons in 2004 to 15 billion gallons mandated for 2015 using a production subsidy per gallon of ethanol financed using a an income tax and by reduction of US agricultural subsidies to zero.

7. Preliminary Results

Commodity	Experiment I	Experiment II	Experiment III
Paddy Rice	2.4	7.2	6.9
Wheat	1.9	1.6	1.4
Coarse Grains	7.2	16.9	16.8
Oilseeds	2.5	2.6	2.6
Sugar Crops	3.5	0.9	0.9
Other Crops	2.5	3.0	3.0
Crude Oil	-2.9	-2.5	-1.2
Gasoline	6.2	4.3	-1.6

Impacts of US Ethanol Mandate on Crop Prices

Acknowledgment

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Experiments	Increase in US Ethanol Supply	Reduction in US gasoline consumption	Reduction in global gasoline consumption	US rebound effect*	Global rebound effect*
Experiment I	7.77	-12.44	-9.36	-1.60	-1.21
Experiment II	7.77	-11.49	-8.62	-1.48	-1.11
Experiment III	7.77	-8.06	-5.92	-1.04	-0.76

*Rebound effect is defined as: Reduction in gasoline / Increase in ethanol

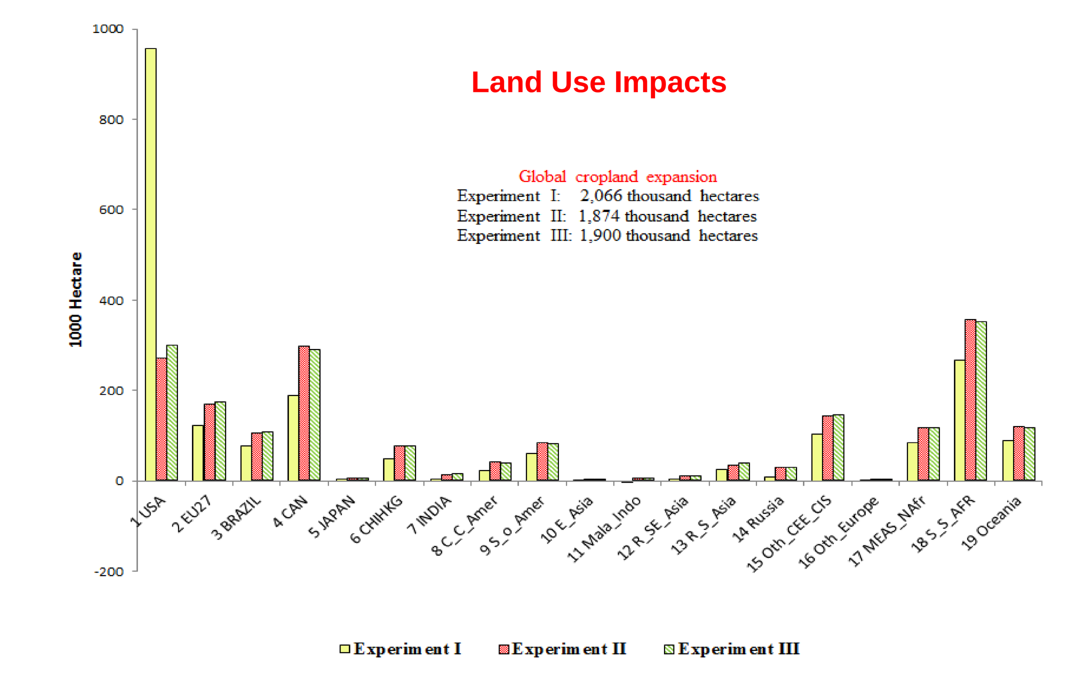
Impacts of US Ethanol Mandate on Consumption of Gasoline *(Billion Gallons)*

Region	Experiment I	Experiment II	Experiment III
USA	1,323	-1,034	-5,018
EU27	-413	505	2,343
BRAZIL	18	67	130
CAN	10	56	141
JAPAN	-101	309	1,054
CHIHKG	222	369	498
INDIA	-65	-12	105
C_C_Amer	228	403	411
S_o_Amer	-157	-80	42
E_Asia	-12	24	78
Mala_Indo	1	30	46
R_SE_Asia	-40	23	111
R_S_Asia	-7	8	44
Russia	-329	-301	-245
Oth_CEE_CIS	-46	4	120
Oth_Europe	-30	6	55
MEAS_NAfr	-640	-515	-223
S_S_AFR	26	74	148
Oceania	14	62	160

Impacts of US Ethanol Mandate on trade balance (in million of 2004 dollars)

Region	Experiment I	Experiment II	Experiment III
USA	-16,822	-15,339	-14,795
EU27	1,952	1,312	132
BRAZIL	173	194	151
CAN	-624	-588	-316
JAPAN	318	-168	-528
CHIHKG	134	67	-44
INDIA	503	448	262
C_C_Amer	-1,597	-1,616	-833
S_o_Amer	-643	-557	-279
E_Asia	411	175	-63
Mala_Indo	-66	-53	-9
R_SE_Asia	221	215	145
R_S_Asia	63	51	25
Russia	-940	-917	-724
Oth_CEE_CIS	42	26	-3
Oth_Europe	-443	-427	-330
MEAS_NAfr	-3,611	-3,503	-2,501
S_S_AFR	-897	-808	-474
Oceania	92	123	134
World	-21,734	-21,365	-20,050

Impacts of US Ethanol Mandate on Welfare (in million of 2004 dollars)



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