AgBioForum, 14(3): 104-110. ©2011 AgBioForum.

Biofuel Policies and Carbon Leakage

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Carbon leakage in the fuel market due to alternative biofuel policies is shown to have two components: a market leakage (or 'indirect output use change') effect and an emissions savings effect. We also distinguish between domestic and international leakage and show how omitting the former can bias leakage estimates. International leakage is always positive, but domestic leakage can be negative with a biofuel mandate. We show leakage due to a tax credit is greater than that of a mandate, while the combination of a mandate and subsidy generates greater leakage than a mandate alone. In general, one gasoline-equivalent gallon of corn ethanol is estimated to replace only 0.35 to 0.50 gallons of gasoline—not one (1.00) gallon as assumed by life-cycle accounting. Taking this market leakage effect into account, we conclude that corn ethanol does not meet the US minimum carbon savings threshold, irrespective of whether the effect of indirect land use change is taken into account.

Key words: biofuels, blend mandate, carbon leakage, domestic leakage, emissions savings, environment, market leakage, tax credit.

Introduction

There has been an overwhelming emphasis on how biofuels cause carbon emissions due to indirect land use change (iLUC).[1] But de Gorter and Just (2009); Drabik and de Gorter (2010); de Gorter (2010); and Drabik, de Gorter, and Just (2010) argue "indirect output use change" (iOUC) in the fuel market can be significantly higher because biofuels do not replace a (mileage equivalent) gallon of gasoline.[2] This article assesses to what extent corn ethanol meets the 0,1 sustainability standard put forward by the US Environmental Protection Agency (EPA), which requires that corn ethanol reduce carbon emissions by 20% relative to gasoline.[3] We analyze a US biofuel mandate, tax credit, and a combination of a mandate and tax credit. For some parameter values, it is theoretically possible that a gasoline-equivalent gallon of ethanol replaces more than a gallon of gasoline under a binding biofuel mandate, possibly offsetting some emissions from iLUC. However, our numerical simulations based on observed data for 2009 fail to show such a result.

This article distinguishes fuel *replaced* versus fuel *displaced* by biofuel policies as well as emphasizes the distinction between domestic and international leakage. If fuel prices decline as a result of produced ethanol, then total fuel consumption increases, resulting in displacement of oil. This is called leakage. The difference between the increase in total fuel use and ethanol supply is the amount of oil replaced.

While market leakage—defined as the observed change in global fuel consumption due to the introduction of ethanol, divided by the amount of ethanol—is always positive with a tax credit; it can be negative with a blend mandate. This means that one gallon of ethanol can replace more than one gallon of gasoline. Our numerical estimates show that one gasoline-equivalent gallon of corn ethanol actually replaces approximately 0.35-0.50 gallons of gasoline. We show that the US corn ethanol does not meet the minimum 20% sustainability standard for carbon savings, irrespective of whether the effect of indirect land use change is taken into account.

The remainder of the article is organized as follows. The next section defines carbon leakage due to biofuel policies and decomposes it into the market leakage (iOUC) and emissions savings effects. Then, the article

1. *Searchinger et al. (2008) were the first to show how US corn ethanol emits more greenhouse gas (GHG) emissions relative to the gasoline it is assumed to replace if changes in the use of land (e.g., converting forest into crop land) are taken into consideration.*
2. *Other papers analyzing iOUC include Bento, Klotz, and Landry (2011); Chen, Huang, and Khanna (2011); Rajagopal, Hochman, and Zilberman (2011); and Thompson, Whistance, and Meyer (2011).*
3. *The 20% figure was an estimate based on "life-cycle accounting" (LCA), a "well to wheel" measure of GHG emissions in the production of gasoline, and a "field to fuel tank" measure for ethanol production (Farrell et al., 2006).*

focuses on market leakage due to a binding blend mandate alone, as well as in combination with a blender's tax credit. We then present numerical estimates of market and carbon leakages for various policy scenarios and estimate the true emissions savings of corn ethanol relative to gasoline. The final section provides concluding remarks.

Carbon Leakage and its Components

Carbon leakage (L_C, in percentage terms) of biofuel policies where ethanol (biodiesel) competes with gasoline (diesel) can be summarized as (Drabik et al., 2010)

$$L_C = [(1/\xi)L_M - 1] \times 100, \tag{1}$$

where ξ denotes an "emissions savings" effect and L_M denotes "market leakage," which is defined in this article as an "indirect output use change" (iOUC) effect. The emissions savings effect represents the cleanliness—in terms of carbon released—of ethanol relative to gasoline. For example, a value of $\xi = 20\%$ means that a gasoline-equivalent gallon of ethanol emits 20% less carbon relative to the same amount of gasoline.

The market leakage effect is defined as the observed change in global fuel consumption resulting from the introduction of ethanol divided by the amount of ethanol. For example, if $L_M = 60\%$, then one gasoline-equivalent gallon of ethanol replaces only 40% of a gallon of gasoline, while total fuel use increases by 0.6 gallons. By the same token, we define carbon leakage as an observed change in global carbon emissions—due to the introduction of ethanol—divided by the intended reduction in carbon corresponding to the ethanol. We compute the intended reduction in carbon by multiplying the quantity of ethanol and the absolute difference between carbon emissions of a gallon of gasoline and an equivalent amount of ethanol.

The structure of Equation 1 makes it convenient to estimate the magnitude of carbon leakage of a biofuel policy; it suffices to focus on estimating the market leakage effect and, given an estimate for the emission savings effect, the magnitude of carbon leakage can be readily calculated. Indeed, this is the approach we adopt in this article.

A close inspection of Equation 1 reveals that if a gallon of ethanol replaces exactly one gallon of gasoline (as assumed by the EPA) then when market leakage is zero, carbon leakage is -100%. This merely means that with the introduction of ethanol, the global carbon emissions decrease (thus, the negative sign) by the intended amount corresponding to the quantity of ethanol. It is therefore natural to take the value of -100% as a threshold to determine whether carbon leakage occurs. If this threshold is exceeded, then there is carbon leakage because the observed reduction in global carbon emissions, if any, is smaller than the intended reduction. It follows that whenever the iOUC effect dominates the emissions savings effect, not only does carbon leakage occur, but global carbon emissions increase because of biofuel production. On the other hand, negative carbon leakage occurs if the iOUC effect is negative (which is only possible with a biofuel mandate), meaning that one gallon of ethanol replaces more than one gallon of gasoline; in other words, global carbon emissions decrease more than one would expect.

To see if corn ethanol meets the EPA sustainability standard (provided that the iOUC effect in the fuel market is considered in addition to the iLUC effect), we adopt a testing criterion elaborated on in Drabik et al. (2010) of

$$\xi - L_M. \tag{2}$$

A negative value of Expression 2 implies that one energy-equivalent gallon of ethanol emits more carbon relative to gasoline when the iOUC effect is taken into account. More importantly, US corn ethanol meets the sustainability standard only if the value of Expression 2 exceeds 20%.

Market Leakage Due to a Blend Mandate

In this section, we present a graphical representation of market leakage due to a biofuel blend mandate. A full mathematical model is provided in de Gorter and Drabik (2011). The home country introducing ethanol is assumed to be an importer of oil as depicted in Figure 1.[4] Prior to the mandate, the world gasoline price P_{G0} is where the home demand for fuel D_H intersects the total gasoline supply S_T facing domestic consumers; the total supply is given by the horizontal sum of the home supply S_H and the foreign excess supply $S_F - D_F$. When a binding mandate of α is implemented, fuel blenders' ethanol demand is implicitly given by the curve αD_H and blending ethanol with gasoline traces out the fuel supply curve S_F^* in the first panel of Figure 1. The inter-

4. *This parallels the US case, as the United States is the world's largest ethanol producer, is an oil importer, and has a consumption mandate that is—in practice—implemented as a blend mandate.*

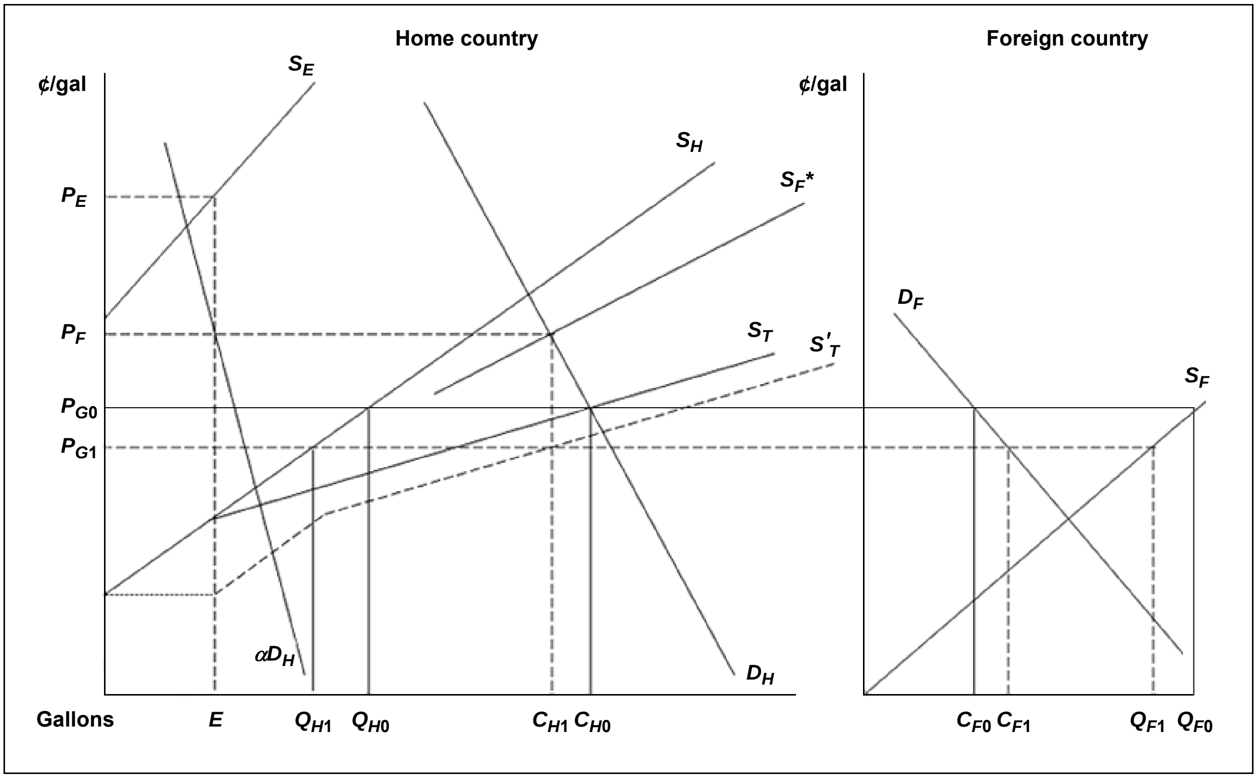

Figure 1. Biofuels leakage with a blend mandate and trade.

section of the domestic fuel demand and supply curves determines the domestic fuel price P_F and the amount of fuel C_{H1}. The amount of ethanol E supporting this equilibrium is where the fuel price intersects the demand curve for ethanol; the ethanol price P_E is then read off the ethanol supply curve S_E. Production of E gallons of ethanol effectively shifts the gasoline supply curve S_T to the right, generating the curve S'_T. The new world gasoline price P_{G1} corresponds to C_{H1} gallons of fuel on S'_T. Domestic and foreign gasoline production fall to Q_{H1} and Q_{F1}, respectively, while foreign gasoline consumption increases by $C_{F0}C_{F1}$ and domestic fuel consumption can either increase or decrease (as depicted in Figure 1) depending on market parameters (de Gorter & Just, 2009). The net increase in world fuel consumption represents market leakage in absolute terms.

The existence of trade in oil (proxied by gasoline in our model) gives rise to a distinction between *domestic* and *international* leakage (de Gorter, 2009). The former occurs because the price of the fuel in the domestic economy (introducing biofuels) alters in response to a biofuel policy and can either decrease (as is always the case with the tax credit where domestic market leakage is positive) or increase/decrease (in the case of a mandate where domestic market leakage is negative/positive). Irrespective of the biofuel policy, international leakage is always positive because the world gasoline (oil) price always decreases, hence inducing higher gasoline consumption outside the home country (the United States). This distinction appears to be important because, for some elasticity values and consumption and production shares, the size of a possibly negative domestic leakage can outweigh the positive international leakage, resulting in one gallon of ethanol replacing more than one gallon of gasoline.

In the case when a blend mandate is implemented alone, i.e., without a tax credit, an increase in the blend mandate has an ambiguous impact on the domestic fuel price as well as on the ethanol market price; the result heavily depends on the market supply and demand elasticities in both countries. The indeterminate effect of a change in the blend mandate on the ethanol market price is directly linked to the effect of a change in the mandate on the fuel price. This happens because with a binding mandate, the amount of ethanol is equal to a fixed proportion of the fuel consumed domestically. An increase in the blend mandate always reduces the world gasoline price because the policy replaces some amount of gasoline; therefore, gasoline production contracts and so does its marginal cost.

The foregoing discussion indicates that the total market leakage due to a blend mandate alone can be either positive or negative (in which case one gallon of ethanol replaces more than one gallon of gasoline), depending on the sign and magnitude of the domestic market leakage since international leakage is always positive.

Tax Credit Combined with a Binding Blend Mandate

Adding a tax credit to a preexisting binding blend mandate always increases the ethanol market price (received by ethanol producers and paid by fuel blenders; de Gorter & Drabik, 2011). This happens because a tax credit reduces the consumer fuel (blend of ethanol and gasoline) price, thus increasing fuel consumption, which necessitates higher ethanol production—an outcome only achievable through a higher market price of ethanol. Also, a higher tax credit combined with a binding blend mandate unequivocally increases the world gasoline price. The explanation is analogous to that above; associated with higher fuel consumption due to the tax credit is higher production of gasoline (owing to a fixed share of gasoline in the final fuel mix). This can only occur under a higher gasoline market price. This implies that a tax credit combined with a blend mandate alleviates (although possibly only marginally) the international leakage caused by a mandate alone, while at the same time it increases the domestic leakage. The overall impact of the addition of a tax credit is thus indeterminate and depends mainly on supply and demand elasticities in both countries.

Unlike the result derived in Drabik et al. (2010)—where market leakage due to addition of a tax credit to a binding consumption mandate results in an infinite market leakage—addition of a tax credit to a binding blend mandate results in a finite market leakage. This happens because the market price of ethanol increases, generating some additional ethanol production, in addition to that due to the mandate.

Numerical Example

We use the data reported in Appendix 5 and elsewhere in Drabik et al. (2010) to run simulations with our model presented in de Gorter and Drabik (2011). Market supply and demand functions are assumed to have constant own-price elasticities. The model is calibrated to reflect the situation in the United States (and the rest of the world, ROW) in 2009. We first simulate leakage effects of a tax credit and a blend mandate alone (Columns 1-4 in Table 1) and then for a combination of a blend mandate with a tax credit (Columns 5-7, Table 1). In addition, for a binding mandate (with or without a tax credit), we distinguish three possible ethanol price premiums of the mandate over the current tax credit: \$0.00, \$0.14, and \$0.34 per gallon, respectively. A zero price premium means the mandate alone would generate the same ethanol price as a tax credit alone. More details on the estimates of these premiums can be found in de Gorter and Just (2010).

A tax credit of \$0.52 per gallon[5] (a federal tax credit of \$0.45 plus an average of a \$0.07-per-gallon state credit) is assumed to generate the same ethanol production, as generated by the model under the 10.21% blend mandate (effective in 2009). We assume two alternative values for the emissions savings effect of the US corn ethanol: ξ_1 = 21% and ξ_2 = 52%. The former takes into account the iLUC effect of ethanol when calculating its carbon savings relative to gasoline, while the latter does not. One gallon of gasoline is assumed to emit 19.4 pounds of CO_2 (US EPA, 2005). We assume no initial ethanol consumption in the United States.

The results show that with a tax credit alone, the world gasoline price (equal to the US fuel price in this case) declines by 3.9% relative to what it was before the policy. This leads to higher US fuel consumption by 1% and higher gasoline consumption in the ROW by 1.6%. However, reflective of the decrease in the gasoline price, world gasoline production declines by 0.8% relative to the baseline.

A change in the composition of the world fuel consumption translates into a change in global CO_2 emissions. Notably, US CO_2 emissions decline by 1.1%, reflecting higher consumption of ethanol and lower consumption of gasoline. On the other hand, CO_2 emissions in the ROW increase by 1.6%. This is because the ROW is assumed to consume only gasoline and consumption rises when the gasoline price declines.

The magnitudes of the market effects of a 10.21% blend mandate (both alone and in combination with a tax credit) differ from the tax credit. The first notable difference is an increase in the US fuel price with the mandate. The price increases in the range of 9% to 13.3% for blend mandate alone and from 5% to 10% when in combination with the tax credit. In both cases, the price increases because fuel consumers have to pay

5. *In the simulations, we use a value of \$0.74 per gallon; however, this is equivalent to the \$0.52 per gallon tax credit on the miles-traveled basis.*

Table 1. Market effects of 2009 US ethanol production under various policy scenarios.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Ethanol price premium (cents per gallon)	**Tax credit***	**Blend mandate**			**Blend mandate & tax credit**		
		0	**14**	**34**	**0**	**14**	**34**
Change in:							
Home fuel price ($/gallon)	-0.07 -3.8%	0.16 9.2%	0.19 10.9%	0.23 13.3%	0.10 5.4%	0.13 7.1%	0.17 9.5%
World gasoline price ($/gallon)	-0.07 -3.8%	-0.09 -5.2%	-0.09 -5.4%	-0.10 -5.6%	-0.09 -4.9%	-0.09 -5.0%	-0.09 -5.2%
Home fuel consumption (tbpd)	83.23 1.0%	-183.62 -2.3%	-215.27 -2.7%	-259.17 -3.2%	-110.44 -1.4%	-143.64 -1.8%	-189.62 -2.3%
Home gasoline consumption (tbpd)	-727.19 -9.0%	-994.03 -12.2%	-1022.46 -12.6%	-1061.87 -13.1%	-928.33 -11.4%	-958.14 -11.8%	-999.43 -12.3%
Home ethanol consumption (tbpd)	810.42	810.42	807.19	802.70	817.89	814.50	809.80
ROW gasoline consumption (tbpd)	444.22 1.6%	608.25 2.2%	625.76 2.2%	650.04 2.3%	567.81 2.0%	586.16 2.1%	611.57 2.2%
World fuel consumption (tbpd)	527.46 1.5%	424.64 1.2%	410.48 1.1%	390.87 1.1%	457.37 1.3%	442.52 1.2%	421.95 1.2%
World gasoline consumption (tbpd)	-282.96 -0.8%	-385.78 -1.1%	-396.70 -1.1%	-411.83 -1.1%	-360.51 -1.0%	-371.98 -1.0%	-387.85 -1.1%
Home CO_2 emissions (ttpd)	-32.14 -1.1%	-130.76 -4.4%	-142.21 -4.7%	-158.09 -5.3%	-104.30 -3.5%	-116.30 -3.9%	-132.93 -4.4%
ROW CO_2 emissions (ttpd)	164.18 1.6%	224.80 2.2%	231.27 2.2%	240.25 2.3%	209.86 2.0%	216.64 2.1%	226.03 2.2%
World CO_2 emissions (ttpd)	132.04 1.0%	94.04 0.7%	89.06 0.7%	82.16 0.6%	105.56 0.8%	100.33 0.7%	93.10 0.7%
Market leakage	65.1%	52.4%	50.9%	48.7%	55.9%	54.3%	52.1%
Domestic share	15.8%	-43.2%	-52.4%	-66.3%	-24.1%	-32.5%	-44.9%
Carbon leakage for ξ = 21%	209.9%	149.5%	142.2%	131.9%	166.3%	158.7%	148.1%
Domestic share	-24.3%	-139.0%	-159.7%	-192.4%	-98.8%	-115.9%	-142.8%
Ethanol savings relative to gasoline for:							
ξ = 21% **	-44.1%	-31.4%	-29.9%	-27.7%	-34.9%	-33.3%	-31.1%
ξ = 52%	-13.1%	-0.4%	1.1%	3.3%	-3.9%	-2.3%	-0.1%

Source: calculated

tbpd = thousand barrels per day; ttpd = thousand tonnes per day

*Note: * Tax credit alone is assumed to generate 810.42 tbpd of ethanol. This corresponds to ethanol production under the 10.21% blend.*

*** A negative number indicates that one gasoline-equivalent gallon of ethanol emits more carbon when the market leakage effect is taken into account.*

for production of ethanol generated under the mandate (unlike with the tax credit when the burden is borne by all taxpayers). A lower fuel price increase reported in Columns 5-7 of Table 1 is because the tax credit constitutes a fuel consumption subsidy.

The world gasoline price decreases more (between 4.8% and 5.6%) than with a tax credit alone. This happens because the incidence of the blend mandate (whether alone or in combination with the tax credit) is to reduce domestic fuel consumption (as opposed to increase it with the tax credit), which reduces the world demand for gasoline, thus, more significantly reducing the gasoline price.

Even though the world gasoline consumption declines approximately by 1% for all blend mandate scenarios, the total CO_2 emissions increase in the range of 60% (for the \$0.34 price premium) to 80% (for the zero price premium). This occurs for two reasons. First, the ROW is assumed to consume only gasoline, which results in higher direct carbon emissions relative to what is observed for the United States and ethanol. Second, there is a country-size effect. The United States consumes approximately one quarter of the world gasoline; this puts a considerable weight on the emissions effect of an increase in gasoline consumption in the ROW.

Market leakage for all considered scenarios lies in the range of 50-65%, with the highest value observed for a tax credit alone and the lowest for the blend mandate alone with an assumed price premium of $0.34. The market leakage values suggest that one gasoline-equivalent gallon of ethanol replaces between 0.35 and 0.50 gallons of gasoline—an estimate that is considerably different from the one-to-one replacement assumption used by the EPA. We also find that the domestic share of the total market leakage is not very significant for the tax-credit-alone scenario (16%) as opposed to other scenarios with the blend mandate. For example, the value of -33% in Column 6 of Table 1 suggests that domestic leakage—negative in that case—accounts for approximately one third of the total market leakage. Negative market leakage corresponds to contraction of domestic fuel consumption as opposed to its expansion in the ROW.

The magnitude of carbon leakage is much higher relative to the market leakage, ranging from 130-210%, with the extremes corresponding to the same scenarios as with the market leakage. The explanation of these, surprisingly high, estimates is that gasoline is not being replaced by a completely CO_2-free fuel. Recall the EPA's assumption that the corn ethanol emits 21% less CO_2 relative to gasoline; the 21% must therefore represent the intended carbon reduction in evaluating the carbon leakage of the ethanol policies. On the other hand, the change in global carbon emissions induced by ethanol could easily offset the intended reduction (as is the case in Table 1), because the ROW always increases its consumption of gasoline that directly produces more carbon than is saved via ethanol. For example, carbon leakage of approximately 160% (Column 6 of Table 1) means that an increase in the global carbon emissions is approximately 1.6 times bigger than the intended carbon reduction due to ethanol.

The last two rows of Table 1 present the true emissions savings of ethanol relative to gasoline when the market leakage (iOUC) effect is taken into consideration. With the value of the emissions saving effect of $\xi = 21\%$ (encompassing the iLUC effect), the corn ethanol does not meet the EPA's standard of 20% carbon reduction relative to gasoline for any policy analyzed. It is because one energy-equivalent gallon of ethanol actually seems to emit 30-40% more carbon relative to gasoline when we account for the iOUC effects of the policy. The threshold is not met even for $\xi = 52$ (that does not take the iLUC into account), although corn ethanol seems to exhibit net carbon-savings between 1 and 3% relative to gasoline when a blend mandate alone has a high price premium.

Conclusions

Leakage is a measure of the ineffectiveness of an environmental policy and is frequently discussed in the context of combating global climate change. We analyze the carbon leakage due to biofuel consumption subsidies (tax credits or tax exemptions) and blend mandates (and their combination). We decompose carbon leakage into "market leakage" (or 'indirect output use change') effect and the "emissions savings" effect. Indirect output use change results from a change in market prices and a subsequent displacement of gasoline and other oil uses by biofuels, while the emissions savings effect represents the relative emissions of biofuels *versus* gasoline.

The international trade framework within which we analyze a blender's tax credit and a blend mandate gives rise to a distinction between domestic and international leakage. With numerical simulations, we show why domestic leakage should be included in leakage estimates of various policies. Because world gasoline prices decline with either biofuel policy, international market leakage is always positive, as is domestic leakage with a tax credit. But domestic market leakage due a mandate can be negative, making it possible that total (domestic plus international) market leakage can be negative.

Our numerical estimates for the United States in 2009 reveal that one energy-equivalent gallon of corn ethanol replaces only 0.35 to 0.50 gallons of gasoline. This translates into the carbon leakage of 130 to 210%, provided iLUC is taken into account and -6 to 25% when excluding iLUC (not shown in Table 1). We find that existing indirect output use change significantly reduces the ability of corn ethanol to save carbon emissions relative to gasoline, and the empirical results for the US policies result in ethanol not meeting the minimum emissions savings threshold of 20% relative to gasoline.

The framework advanced in this article assumes the supply curve for gasoline is fixed. But an emerging literature on the Green paradox suggests that the introduction of biofuels shifts the gasoline supply curve down as owners of non-renewable resources worry about the rate of capital gains on these resources and thus are motivated to extract their stocks of oil more rapidly in order to convert a larger portion of their wealth into cash and securing it as financial capital (Eichner & Pething, 2009; Grafton, Kompas & van Long, 2010; Hoel, 2008; Sinn, 2008, 2009). So the estimates of leakage in this article may be underestimated if aspects of the Green paradox are not included.

References

Bento, A.M., Klotz, R., & Landry, J.R. (2011, July). *Are there carbon savings from US biofuel policies? Accounting for leakage in land and fuel markets*. Paper presented at the 2011 Agricultural & Applied Economics Association Annual Meeting, Pittsburgh, Pennsylvania.

Chen, X., Huang, H., & Khanna, M. (2011, July). *Land use and greenhouse gas implications of biofuels: Role of technology and policy.* Paper presented at the 2011 Agricultural & Applied Economics Association Annual Meeting, Pittsburgh, Pennsylvania.

de Gorter, H. (2009). *Integrating developing country agriculture into global climate change mitigation efforts*. In Aziz Elbehri & Alexander Sarris (Eds.) Non-Distorting Farm Support to Enhance Global Food Production, Rome, Italy: Food and Agriculture Organization (FAO).

de Gorter, H. (2010). Does US corn-ethanol really reduce emissions by 21%? Lessons for Europe. *Biofuels*, *1*(5), 671-673.

de Gorter, H., & Drabik, D. (2011, June). *A proper methodology to measure carbon leakages from 'Indirect Output Use Change' (IOUC) due to alternative biofuel policies*. Paper presented at the 15th International Consortium on Applied Bioeconomy Research (ICABR) Conference, Frascati (Rome), Italy.

de Gorter, H., & Just, D.R. (2009). The economics of a blend mandate for biofuels. *American Journal of Agricultural Economics*, *91*(3), 738-750.

de Gorter, H., & Just, D.R. (2010). The social costs and benefits of biofuels: The intersection of environmental, energy and agricultural policy. *Applied Economic Perspectives and Policy*, *32*(1), 4-32.

Drabik, D., & de Gorter, H. (2010, June). *Biofuels and leakages in the fuel market*. Paper presented at the International Agricultural Trade Research Consortium: Climate Change in World Agriculture: Mitigation, Adaptation, Trade and Food Security, Stuttgart-Hohenheim, Germany.

Drabik, D., de Gorter, H., & Just, D.R. (2010, November). *The implications of alternative biofuel policies on carbon leakage* (Working Paper 2010-22). Ithaca: Cornell University, Charles H. Dyson School of Applied Economics and Management.

Eichner, T., & Pethig, R. (2009, February). *Carbon leakage, the Green Paradox and perfect future markets* (CESifo Working Paper No. 2542). Munich, Germany: Center for Economic Studies (CES) and the Ifo Institute.

Farrell, A., Plevin, R., Turner, B., Jones, A., O'Hare, M., & Kammen, D. (2006). Ethanol can contribute to energy and environmental goals. *Science*, *311*(5760), 506-508.

Grafton, R.Q., Kompas, T., & Van Long, N. (2010). *Biofuels subsidies and the Green Paradox* (CESIFO Working Paper No. 2960). Munich, Germany: CES and the Ifo Institute.

Hoel, M. (2008). *Bush meets hotelling: Effects of improved renewable energy technology on greenhouse gas emissions* (CESifo Working Paper No. 2492). Munich, Germany: CES and the Ifo Institute.

Rajagopal, D., Hochman, G., & Zilberman, D. (2011). Indirect fuel use change (IFUC) and the life cycle environmental impact of biofuel policies. *Energy Policy*, *39*(1), 228-233.

Searchinger, T., Heimlich, R., Houghton, R., Dong, F., Elobeid, A., Fabiosa, J., et al. (2008). Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land use change. *Science*, *319*(5867), 1238-1240.

Sinn, H.-W. (2008). Public policies against global warming: A supply-side approach. *International Tax and Public Finance*, *15*(4), 360-394.

Sinn, H.-W. (2009). The Green Paradox. *CESifo Forum*, *10*(3), 10-13.

Thompson, W., Whistance, J., & Meyer, M. (2011). Effects of US biofuel policies on US and world petroleum product markets with consequences for greenhouse gas emissions. *Energy Policy*, *39*(9), 5509-5518.

US Environmental Protection Agency (EPA). (2005, February). *Emission facts: Average carbon dioxide emissions resulting from gasoline and diesel fuel* (EPA 420-F-05-001). Washington, DC: Author. Available on the World Wide Web: http://www.epa.gov/oms/climate/420f05001.htm.

Acknowledgement

This project was supported by the National Research Initiative of the National Institute of Food and Agriculture, US Department of Agriculture (USDA), Grant # 121-8520 and by the Cornell University Agricultural Experiment Station federal formula funds, Project No. NYC-121-7438 received from Cooperative State Research, Education, and Extension Service, USDA. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the USDA. Dusan Drabik also acknowledges financial support provided by the Slovak Ministry of Education, Project No. VEGA 1/0714/09. We wish to thank Justus Wesseler, Guest Editor of *AgBioForum*, and an anonymous reviewer for their constructive comments and suggestions.