The Implications of Alternative Biofuel Policies on Carbon Leakage

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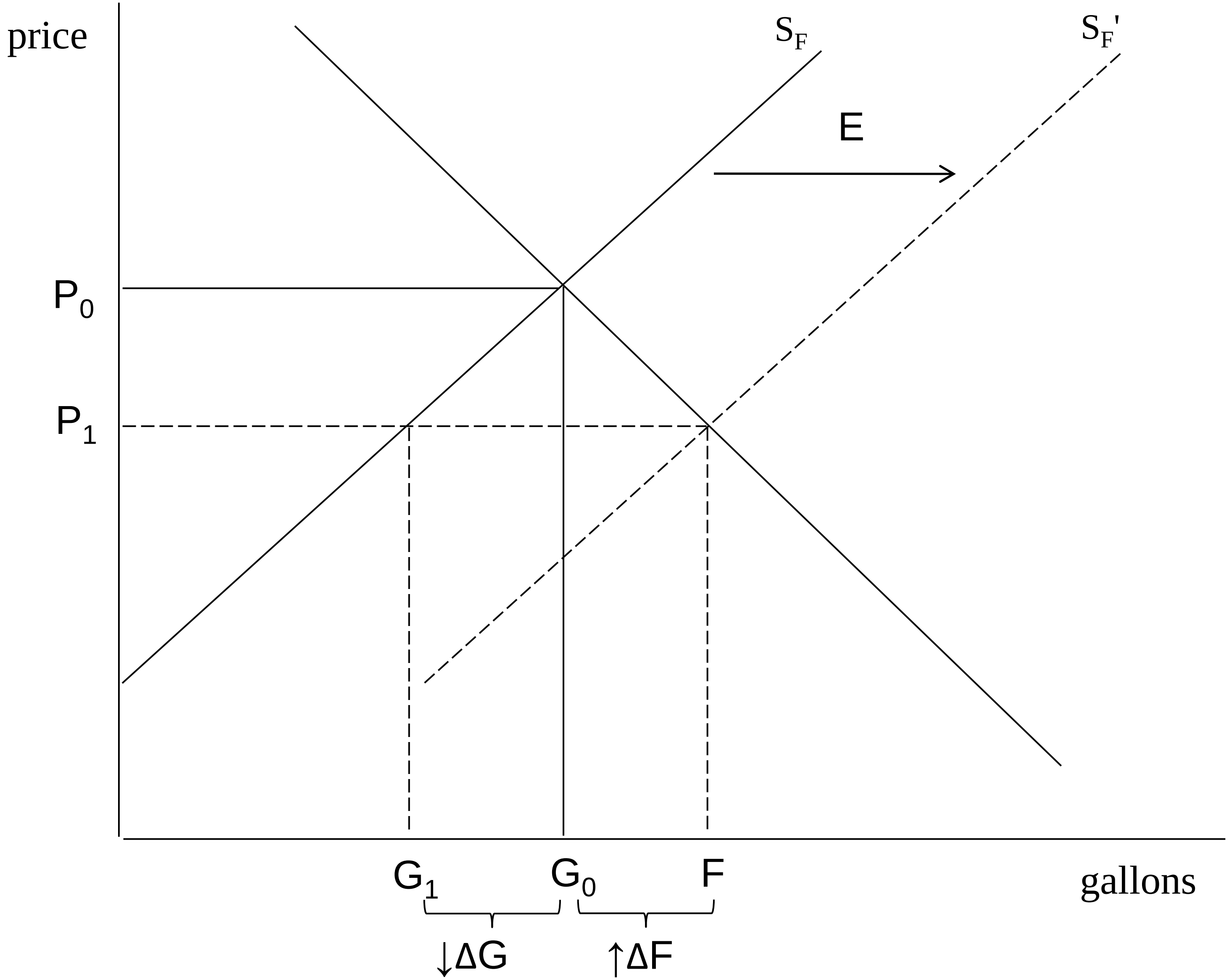
Motivation

- Carbon leakage important because can undermine environmental policies
- Many studies for cap & trade (e.g., Frankel 2009), reduced deforestation and land degradation - REDD (e.g., Murray Murray 2008) and indirect land use change (iLUC) generated from biofuels policies (e.g., Searchinger et al. 2008)
- No studies on leakage of biofuels in fuel market itself, i.e., “indirect output use change” (iOUC) (except for papers by de Gorter, Drabik and Just in 2009; 2010)
- Issue is does corn-ethanol meet the 20% reduction threshold even with recent EPA’s revision of LCA that includes iLUC?

Presentation Overview

- Definition of leakage in the fuel market (market *vs* carbon leakage)
- True emissions of ethanol
- Leakage due to a tax credit
- Leakage due to a consumption mandate
- Leakage due to combination of tax credit & mandate
- Numerical estimate of leakage
- Concluding remarks

Effect of Ethanol in Fuel Market



Quantifying Leakage in the Fuel Market

$$L_M = \frac{\Delta C_F}{E} = \frac{E + \Delta C_G}{E}$$

- Call it "market leakage"
- Measures by how many gallons fuel consumption increases when 1 gasoline-equivalent (g-e) gallon of ethanol added to fuel market
- e.g.: If $L_M = 0.7$, then 1 g-e gallon of ethanol replaces only 0.3 gallons of gasoline
- Usually (+), but can be (–) with a mandate

Adjusting for Carbon…

- IPCC definition of carbon leakage:

$$\frac{\text{increase in GHG elsewhere}}{\text{GHG directly reduced by the policy}}$$

- We follow the concept, BUT recognize also domestic leakage AND allow for negative carbon leakage:

$$\frac{\Delta \text{ in global carbon emissions}}{\text{reduction in carbon due to biofuels}}$$

Emissions Savings Effect

$$\xi = \frac{e_G - e_E}{e_G}$$

- General definition; allows for various approaches to compute ξ:
  - Compare instantaneous amounts of carbon released when a fossil fuel and biofuel are combusted.
  - Biofuels net zero in CO_2 b/c carbon sequestered during photosynthesis = carbon released @ combustion; ξ=100%
  - LCA measures carbon emissions “field-to-tank” for biofuels; ξ=52% for corn ethanol
  - LCA + iLUC; ξ=21%

Carbon Leakage

$$L_C = \frac{(1-\xi)e_G E + e_G \Delta C_G}{\xi e_G E} = \ldots = \frac{1}{\xi} L_M - 1$$

- Remember, ethanol only saves ξ (important especially for ξ < 1)
- Assumptions:
  - No "technical leakage": emissions of gasoline = everywhere
  - Ethanol & gasoline are perfect substitutes in consumption (in energy equivalent)
  - All ethanol saves the same amount of carbon relative to gasoline, i.e., corn ethanol & sugar cane ethanol emit the same amount of carbon

Carbon Leakage (cont'd)

$$L_C = \frac{1}{\xi} L_M - 1$$

- Two determinants:
  - emissions savings effect
  - market leakage, a.k.a. **I**ndirect **O**utput **U**se **C**hange (iOUC)
- So focus on market leakage and then simply convert

Carbon Leakage (cont'd)

$$L_C = \frac{1}{\xi} L_M - 1$$

- Important cases:
  - $L_M = \xi$, then Δ in global emissions = 0
  - $L_M > \xi$, then Δ in global emissions > 0
  - $L_M < \xi$, then Δ in global emissions < 0
  - $L_M = 0$, then $L_C = -100\%$: global emissions ↓ by as much as intended
  - $L_M < 0$ (only possible w/ a mandate), then $L_C < -100\%$: get higher ↓ than intended ~ "negative leakage"

True Emissions of Ethanol

- Need to consider **not only "own" emissions**, but **also** the **change in emissions due to iOUC**:

$$\frac{\overbrace{(1-\xi)e_G E}^{\text{own emissions}} + \overbrace{(G_1 - G_0 + E)e_G}^{\text{emissions due to iOUC}}}{E} = \ldots = (1-\xi+L_M)e_G$$

- Need to update the emissions savings effect:

$$\frac{e_G - (1-\xi+L_M)e_G}{e_G} = \xi - L_M$$

True Emissions of Ethanol (cont'd)

- Interpretation:
  - $\xi > L_M$, then ethanol saves emissions
  - $\xi = L_M$, then no change in emissions
  - $\xi < L_M$, then ethanol emits more than gasoline

- Implication: $L_M > 0$ always makes ethanol emit less *vs* gasoline than originally expected

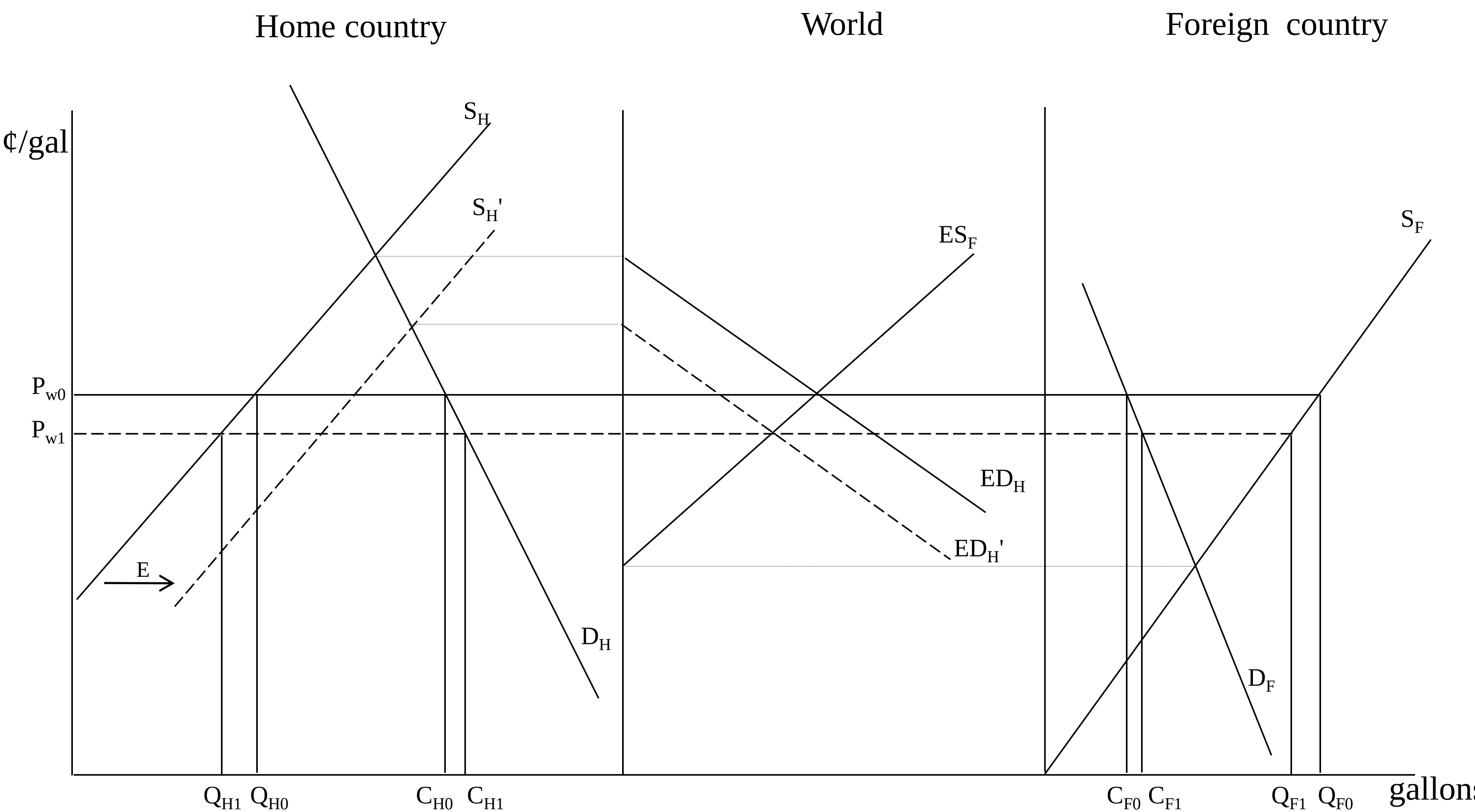
Location of Leakage

- Domestic
- International

- IPCC focuses only on international, but domestic can be substantial, or even negative so need to take into consideration.

Leakage with a Tax Credit

Biofuels Leakage with a Tax Credit and Trade



Market Leakage w/ a Tax Credit

$$L_M^{\tau} = \frac{\rho\eta_{DH} + (1-\rho)\eta_{DF}}{\rho\eta_{DH} + (1-\rho)\eta_{DF} - \phi\eta_{SH} - (1-\phi)\eta_{SF}} \geq 0, \leq 1$$

ρ - share of Home (*H*) country in world gasoline consumption

ϕ- share of the Home country in world gasoline production

η – elasticity

D – demand

S – supply

H – Home

F – Foreign country

Market Leakage w/ a Tax Credit (cont'd)

Change in market leakage with respect to:	Sign of the effect	Note
Domestic fuel demand elasticity (η_{DH})	(-)	unambiguous sign
Foreign fuel demand elasticity (η_{DF})	(-)	unambiguous sign
Domestic gasoline supply elasticity (η_{SH})	(-)	unambiguous sign
Foreign gasoline supply elasticity (η_{SF})	(-)	unambiguous sign
Domestic consumption share in world gasoline consumption (ρ)	(+)	for $\eta_{DH} < \eta_{DF}$
	(-)	for $\eta_{DH} > \eta_{DF}$
Domestic production share in world gasoline production (ϕ)	(+)	for $\eta_{SH} < \eta_{SF}$
	(-)	for $\eta_{SH} > \eta_{SF}$

Market Leakage w/ a Tax Credit (cont'd)

Market leakage ↓ as:

- Demand for fuel in either country becomes less elastic
- Supply of gasoline in either country becomes more elastic

Market leakage ↑ w/:

- Higher consumption share of Home country if the demand for fuel in that country is more elastic than it is in the Foreign country
- Higher gasoline production provided the supply elasticity in Home country is lower than it is in the Foreign country
  - Implication: the attempts of countries to be less dependent on oil by progressively consuming more ethanol are likely to increase market leakage if the domestic consumers are less price sensitive than the consumers in the rest of the world

Domestic *vs* International Leakage

$$\frac{L_M^D}{L_M^I} = \left(\frac{\rho}{1-\rho} \right) \frac{\eta_{DH}}{\eta_{DF}}$$

Domestic *L* becomes more important as:

- Share of gasoline consumption of the Home country ↑
- Relative demand elasticity of the Home country ↑

Implication:

- If a country producing ethanol consumes a substantial share of world gasoline, the bias from ignoring dom. L might be substantial
- If dom. D for fuel is more elastic and only int'l L estimated, then result likely to be an underestimate of the true value

Country Size and Market Leakage

Assume 2 situations for the Home country, *A* and *B*, such that

$$\left(dP_G/dE\right)^A < \left(dP_G/dE\right)^B$$

then market leakage seen by the Home country in situation *A* is lower than in situation *B* whenever:

$$\eta_{DH}^{B} D_H^B + \eta_{DF}^{*} D_F^{*} < \eta_{DH}^{A} D_H^A + \eta_{DF} D_F$$

- So ambiguous link between country size and leakage

Market Leakage for a Small Country

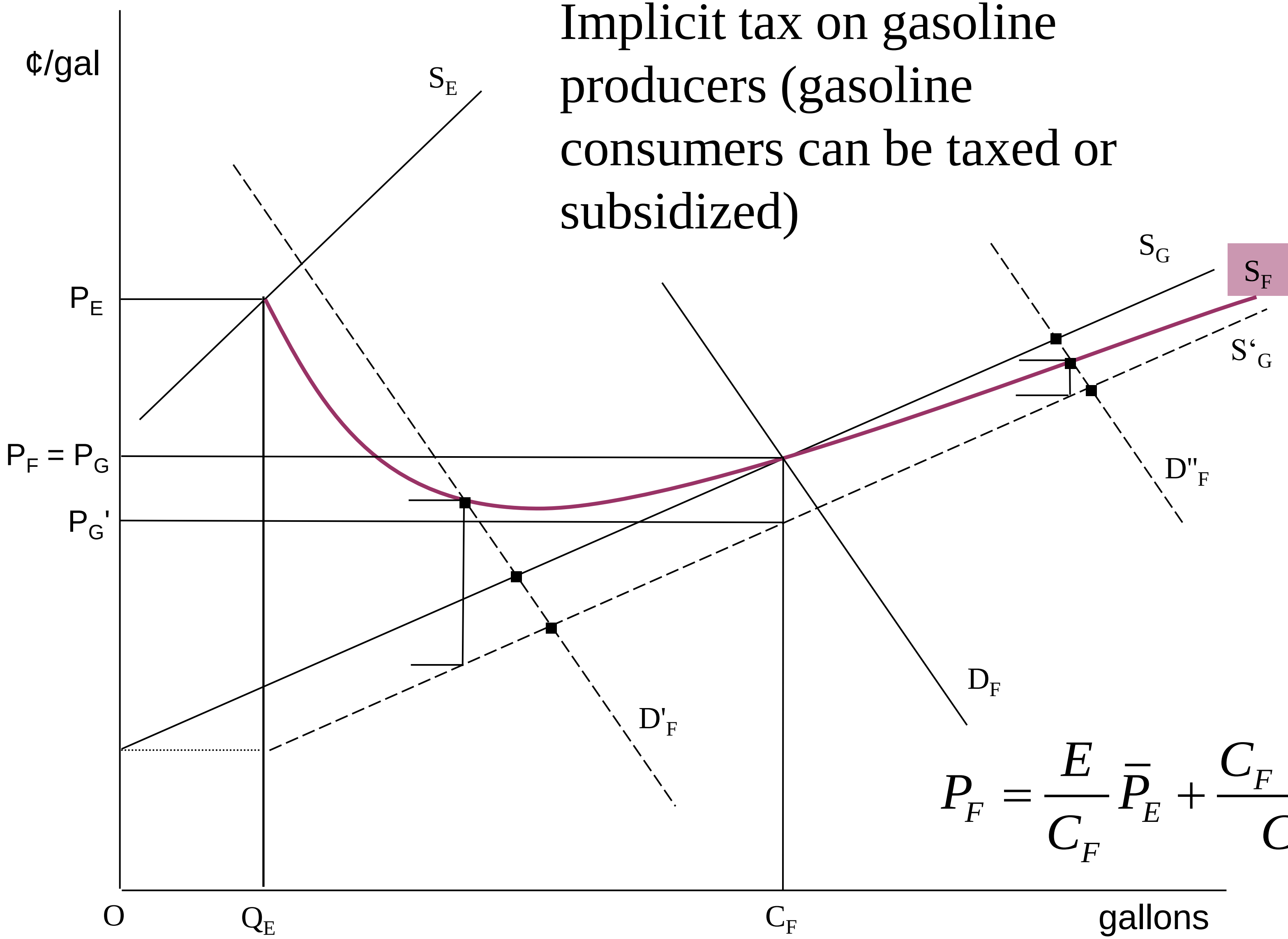
- Small country faces a perfectly elastic excess demand/ excess supply curve

- Three cases:
  - Small importer if $\eta_{SF} \rightarrow \infty$; $L_M = 0$
  - Small exporter if $\eta_{DH} \rightarrow -\infty$; $L_M = 100\%$
  - Independent of trade position if $\rho \rightarrow \phi$; $0 \leq L_M \leq 100\%$

Leakage with a Consumption Manadate

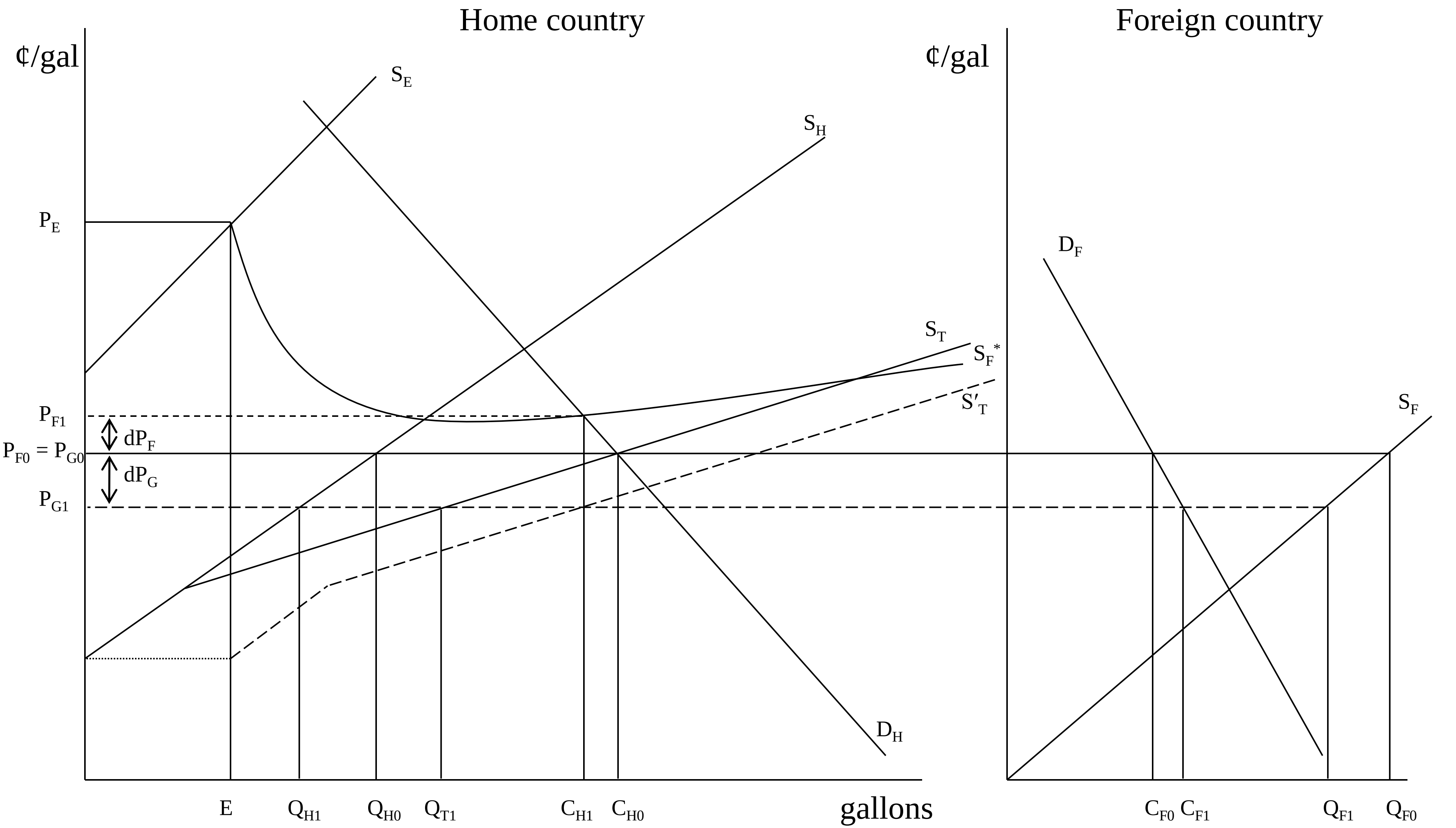
Consumption mandate with an endogenous oil price

Implicit tax on gasoline producers (gasoline consumers can be taxed or subsidized)



$$P_F = \frac{E}{C_F}\bar{P}_E + \frac{C_F - E}{C_F}P_G$$

Biofuels Leakage with a Consumption Mandate and Trade



Market Leakage when a Tax Credit Added to a Binding Cons. Mandate

- A binding consumption mandate + tax credit => leakage **due to the tax credit alone** is infinity

- Why? No additional ethanol Q if consumption mandate binding. So no gasoline is replaced by ethanol due to tax credit. But additional gasoline is consumed. So numerator finite but denominator zero

- But combination of mandate and tax credit produces finite leakage because ethanol due to mandate replaces some gasoline

Market Leakage when a Tax Credit Added to a Binding Cons. Mandate

What if have a tax credit = price premium necessary to generate the mandated amount of ethanol with the tax credit alone?

- **if the country is small** in world oil markets, then the tax credit **exactly offsets** the reduction in gasoline consumption due to the mandate and market leakage of both policies combined is zero

- **if the country is large** in world oil markets, then the tax credit **more than offsets** the reduction in gasoline consumption due to the mandate and market leakage of both policies combined is positive

Table 3: Baseline Values of Market and Carbon Leakages under Trade vs Autarky *

	International trade			Autarky	True emissions savings of ethanol**	
	(I.) Total (our definition)	(II.) Domestic share	(III.) IPCC definition	(IV.)	(V.) Trade	(VI.) Autarky
Market Leakage						
Tax credit	0.65	16%	0.61	0.57		
Mandate	0.61	-2%	0.61	0.52		
Tax credit w/ binding mandate	0.64	9%	0.61	0.54		
Carbon Leakage						
Incl. iLUC (ξ=0.21)						
Tax credit	2.09	-24%	1.72	1.69	-0.44	-0.36
Mandate	1.90	-56%	1.43	1.45	-0.40	-0.31
Tax credit w/ binding mandate	2.07	-36%	1.59	1.55	-0.43	-0.33
Excl. iLUC (ξ=0.52)						
Tax credit	0.25	-321%	0.58	0.09	-0.13	-0.05
Mandate	0.17	-619%	0.59	-0.01	-0.09	0.00
Tax credit w/ binding mandate	0.24	-408%	0.58	0.03	-0.12	-0.02

Source: calculated

* Magnitudes of leakage multiplied by 100 are interpreted as percentage.

** The values are calculated as ξ minus total market leakage (with international trade or under autarky). For example, the value -0.43 indicates that one gasoline-equivalent gallon of ethanol emits 1.43 times more carbon emissions than one gallon of gasoline

Baseline parameters: $\rho=0.224$, $\varphi=0.074$, $\delta=1.440$, $\eta_{DH}=-0.26$, $\eta_{DF}=-0.40$, $\eta_{SH}=0.20$, $\eta_{SF}=0.20$

Domestic share figures are calculated as follows:

For market leakage: change in domestic fuel consumption is divided by change in world fuel consumption (all multiplied by 100).

For carbon leakage: the numerator of the ratio is equal to carbon intensity of ethanol (relative to gasoline) times quantity of ethanol plus change in domestic gasoline consumption; the denominator is equal to carbon intensity of ethanol times quantity of ethanol plus change in world gasoline consumption (all multiplied by 100).

Table 4a: Sensitivity Analysis for Magnitude of Leakage Including iLUC (ξ=0.21): Trade *

Parameters values unless otherwise specified: ρ = 0.224, φ = 0.074, δ = 1.44, η_{SH} = 0.2, η_{SF} = 0.2, η_{DH} = -0.26, η_{DF} = -0.4

Home supply elasticity of gasoline (η_{SH})	**0.10**	**0.20**	**0.40**	**0.60**	**0.80**	**1.00**	**1.20**	**1.40**	**1.60**	**1.80**	**2.00**
Market leakage: Tax credit	0.66	0.65	0.63	0.62	0.60	0.59	0.57	0.56	0.55	0.54	0.53
Consumption mandate	0.62	0.61	0.59	0.57	0.56	0.54	0.52	0.51	0.50	0.48	0.47
Carbon leakage: Tax credit	2.13	2.09	2.01	1.93	1.86	1.80	1.73	1.67	1.61	1.55	1.50
Consumption mandate	1.94	1.90	1.81	1.72	1.65	1.57	1.50	1.43	1.36	1.30	1.24
Foreign supply elasticity of gasoline (η_{SF})	**0.10**	**0.20**	**0.40**	**0.60**	**0.80**	**1.00**	**1.20**	**1.40**	**1.60**	**1.80**	**2.00**
Market leakage: Tax credit	0.77	0.65	0.49	0.39	0.33	0.28	0.25	0.22	0.20	0.18	0.16
Consumption mandate	0.75	0.61	0.43	0.32	0.25	0.20	0.16	0.13	0.11	0.09	0.07
Carbon leakage: Tax credit	2.69	2.09	1.33	0.87	0.56	0.34	0.17	0.05	-0.06	-0.14	-0.21
Consumption mandate	2.56	1.90	1.05	0.54	0.20	-0.05	-0.24	-0.38	-0.50	-0.59	-0.67
Home demand elasticity of fuel (η_{DH})	**-0.10**	**-0.20**	**-0.40**	**-0.60**	**-0.80**	**-1.00**	**-1.20**	**-1.40**	**-1.60**	**-1.80**	**-2.00**
Market leakage: Tax credit	0.62	0.64	0.67	0.69	0.71	0.73	0.74	0.76	0.77	0.78	0.79
Consumption mandate	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
Carbon leakage: Tax credit	1.97	2.05	2.17	2.28	2.38	2.47	2.54	2.61	2.67	2.72	2.77
Consumption mandate	1.90	1.90	1.90	1.90	1.89	1.89	1.89	1.89	1.89	1.89	1.89
Foreign demand elasticity of fuel (η_{DF})	**-0.10**	**-0.20**	**-0.40**	**-0.60**	**-0.80**	**-1.00**	**-1.20**	**-1.40**	**-1.60**	**-1.80**	**-2.00**
Market leakage: Tax credit	0.40	0.52	0.65	0.72	0.77	0.81	0.83	0.85	0.87	0.88	0.89
Consumption mandate	0.34	0.46	0.61	0.69	0.75	0.78	0.81	0.83	0.85	0.87	0.88
Carbon leakage: Tax credit	0.93	1.46	2.09	2.45	2.68	2.84	2.96	3.05	3.13	3.19	3.24
Consumption mandate	0.60	1.19	1.90	2.30	2.55	2.74	2.87	2.97	3.05	3.12	3.18

Source: calculated

* Magnitudes of leakage multiplied by 100 are interpreted as percentage.

Note: Shaded areas pertain to baseline.

Table 4b: Sensitivity Analysis for Magnitude of Leakage Excluding iLUC (ξ=0.52): Trade * **

Parameters values unless otherwise specified: ρ = 0.224, φ = 0.074, δ = 1.44, η_{SH} = 0.2, η_{SF} = 0.2, η_{DH} = -0.26, η_{DF} = -0.4

Home supply elasticity of gasoline (η_{SH})	**0.10**	**0.20**	**0.40**	**0.60**	**0.80**	**1.00**	**1.20**	**1.40**	**1.60**	**1.80**	**2.00**
Carbon leakage: Tax credit	0.26	0.25	0.21	0.18	0.16	0.13	0.10	0.08	0.05	0.03	0.01
Consumption mandate	0.19	0.17	0.13	0.10	0.07	0.04	0.01	-0.02	-0.05	-0.07	-0.09
Foreign supply elasticity of gasoline (η_{SF})	**0.10**	**0.20**	**0.40**	**0.60**	**0.80**	**1.00**	**1.20**	**1.40**	**1.60**	**1.80**	**2.00**
Carbon leakage: Tax credit	0.49	0.25	-0.06	-0.25	-0.37	-0.46	-0.53	-0.58	-0.62	-0.65	-0.68
Consumption mandate	0.44	0.17	-0.17	-0.38	-0.52	-0.62	-0.69	-0.75	-0.80	-0.83	-0.87
Home demand elasticity of fuel (η_{DH})	**-0.10**	**-0.20**	**-0.40**	**-0.60**	**-0.80**	**-1.00**	**-1.20**	**-1.40**	**-1.60**	**-1.80**	**-2.00**
Carbon leakage: Tax credit	0.20	0.23	0.28	0.33	0.37	0.40	0.43	0.46	0.48	0.50	0.52
Consumption mandate	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Foreign demand elasticity of fuel (η_{DF})	**-0.10**	**-0.20**	**-0.40**	**-0.60**	**-0.80**	**-1.00**	**-1.20**	**-1.40**	**-1.60**	**-1.80**	**-2.00**
Carbon leakage: Tax credit	-0.22	-0.01	0.25	0.39	0.49	0.55	0.60	0.64	0.67	0.69	0.71
Consumption mandate	-0.35	-0.11	0.17	0.33	0.44	0.51	0.56	0.60	0.64	0.66	0.69

Source: calculated

* Market leakage is the same as in Table 4a.

** Magnitudes of leakage multiplied by 100 are interpreted as percentage.

Note: Shaded areas pertain to baseline.

Conclusions

- Leakage is a measure of ineffectiveness of an environmental policy
- Two components of carbon leakage: *market leakage* (iOUC) effect and *emissions savings* effect
- This holds both for partial and general equilibrium
- Need to analyze both *domestic* and *international* leakage
- International leakage always (+), as is domestic leakage with a tax credit. But domestic leakage with a mandate can be (-), making it possible that total leakage can be (-)

Conclusions (cont'd)

- Leakage typically more sensitive to elasticities than to market shares, and is especially more sensitive to changes in market parameters of the country not introducing biofuels

- Being a relatively smaller country in world oil markets does not automatically imply a higher leakage

- For the same amount of ethanol, market leakage due to a tax credit is always > due to a binding consumption mandate

- Combination of a binding mandate and a tax credit produces > leakage than a mandate alone

Conclusions (cont'd)

- Positive market leakage (iOUC) always reduces carbon savings of ethanol relative to gasoline
- 1 g-e gallon of corn ethanol in the U.S. highly likely replaces < 1 gallon of gasoline. We estimate 0.35 to 0.40 gallons
- But this can be an underestimate if consider Sinn's "*Green Paradox*"

Conclusions (cont'd)

So what is the implication?

- U.S. corn ethanol does not meet the sustainability standard!

But does it matter? NO

- Because the standard is 0,1 threshold based on LCA which has a lot of problems and does not consider a lot of things

So what to do?

- One example: use inter-temporal cost benefit analysis instead (upfront emissions and emissions forgone are cost and net sequestration of biofuels is the benefit)