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Global Land Use Changes due to US Cellulosic Biofuel Program: A Preliminary Analysis

And Updated Corn Ethanol, Biodiesel, and Sugarcane Ethanol Estimates

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Steps in Our Analysis

- Introduce the first generation if biofuels into version 7 of the GTAP data base (2004). All the prior work was done on ver. 6 (2001).
- Introduce new cellulosic biofuels and their supporting activities into the model.
- Add greater flexibility in acreage switching among crops in the US in response to price changes.
- Include an endogenous yield adjustment for cropland pasture in response to changes in cropland pasture rent.

New GTAP-BIO Database

- Introduced 2004 global production, consumption, and trade for first generation biofuels.
- Updated land use, land cover, and land rent headers to 2004.
- Following the previous work, created new industries for corn ethanol, sugarcane ethanol, and biodiesel.
- Modified the basic GTAP database as was done previously:
  - Split GTAP food industry into food and feed industries,
  - Split GTAP vegetable oil into crude and refined vegetable oil industries.
- Introduced by-products into the 2004 database.

Introduced Cellulosic Feedstock and Biofuels Industries into Version 7

- Corn stover industry which collects corn stover from corn land and delivers it to the cellulosic biofuel industry.
- Dedicated crop industries (miscanthus and switchgrass) produce feedstock and deliver it to biofuel industries.
- Introduced a biofuel (bio-gasoline) processing industry and ethanol for each feedstock with identical cost structures.
- Since none of these industries exist, we developed consensus estimates using experts from Argonne, NREL, and Purdue for dedicated energy crop yields and conversion technologies.

Biofuel Production Costs

Cost Items	FeedStock ($ / dry short ton)	Pathways		
		Thermo - Gasoline	Bio - Ethanol - Stover	Bio - Ethanol - Dedicated Crops
Capital cost ($/gal.)		$1.14	$0.51	$0.57
Operating cost ($/gal.)		$0.49	$1.34	$1.52
Feedstock cost:				
Stover ($/gal)	$89.47	$1.49	$1.19	
Switchgrass ($/gal)	$121.37	$2.02		$1.62
Miscanthus ($/gal)	$126.03	$2.10		$1.68
Total cost - stover		$3.12	$3.05	
Total cost - switchgrass		$3.65		$3.71
Total cost - miscanthus		$3.73		$3.77

- Assumed that the conversion rate is 60 gallons of bio-gasoline per metric ton of feedstock and 75 gallons of ethanol per dry ton.

Cost Structures for Feedstocks

Cost Items	Corn Stover	Miscanthus	Switchgrass
Fertilizer	22.7	14.0	15.6
Transportation	33.5	25.4	28.4
Fuel	3.4	4.6	5.1
Payments to seed company	0.0	6.7	1.7
Other costs	7.0	7.5	8.0
Labor	10.0	10.7	11.5
Land	0.0	2.7	5.8
Capital (including profit)	23.3	28.5	23.9
Total	100.0	100.0	100.0

Cost Structures for Corn Stover, Miscanthus, and Switchgrass

Cost items	Bio-gasoline			Ethanol		
	Miscanthus	Switchgrass	Corn stover	Miscanthus	Switchgrass	Corn stover
Feedstock	54.6	51.9	47.7	42.9	40.2	39.2
Chemicals	0.0	0.0	0.0	15.6	16.3	18.8
Energy	1.0	1.0	1.1	4.1	4.2	4.9
Other costs	10.5	11.1	12.1	17.5	18.3	15.0
Labor	2.2	2.4	2.6	4.4	4.6	5.3
Capital	31.8	33.7	36.6	15.6	16.3	16.9
Total	100.0	100.0	100.0	100.0	100.0	100.0

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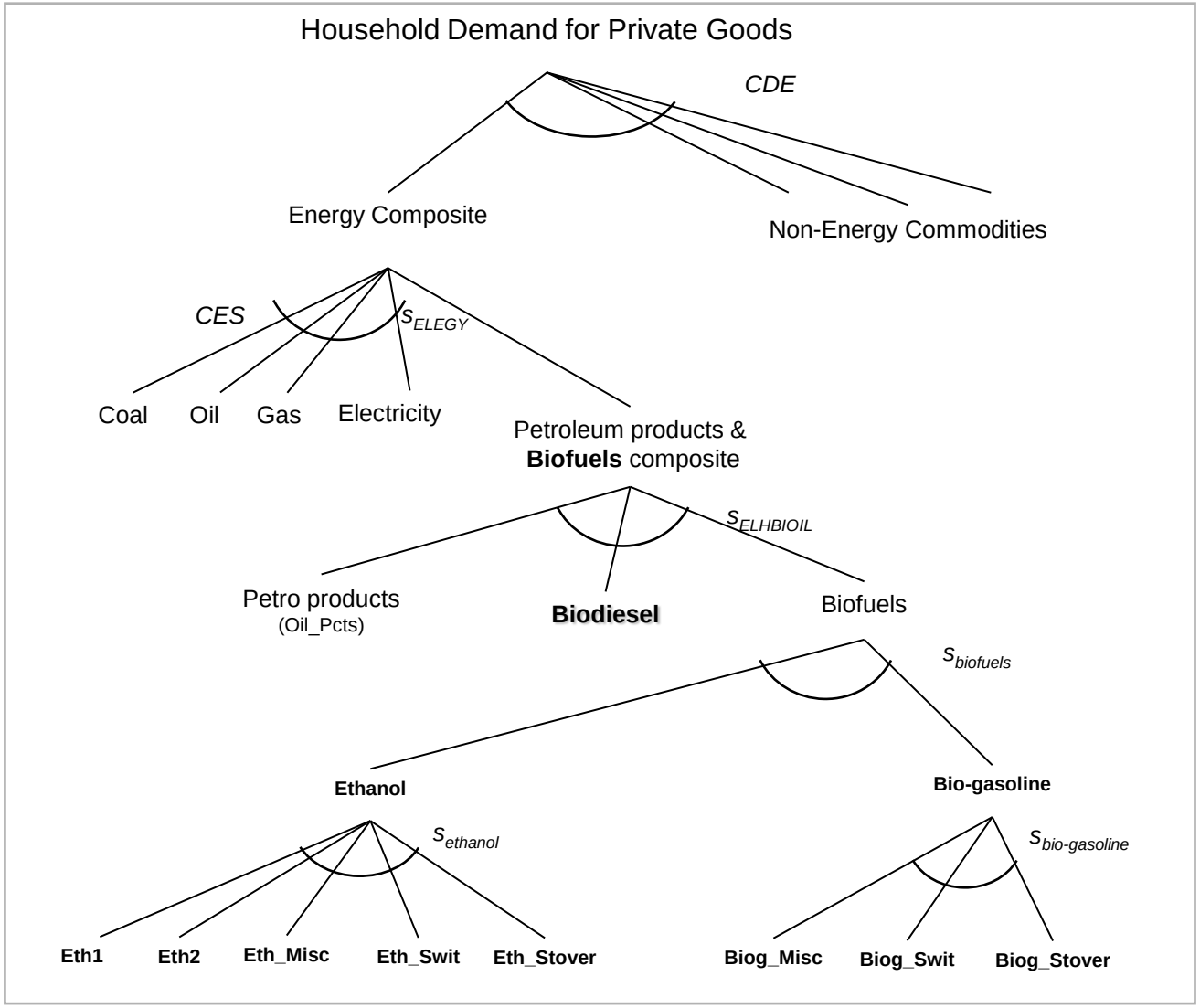
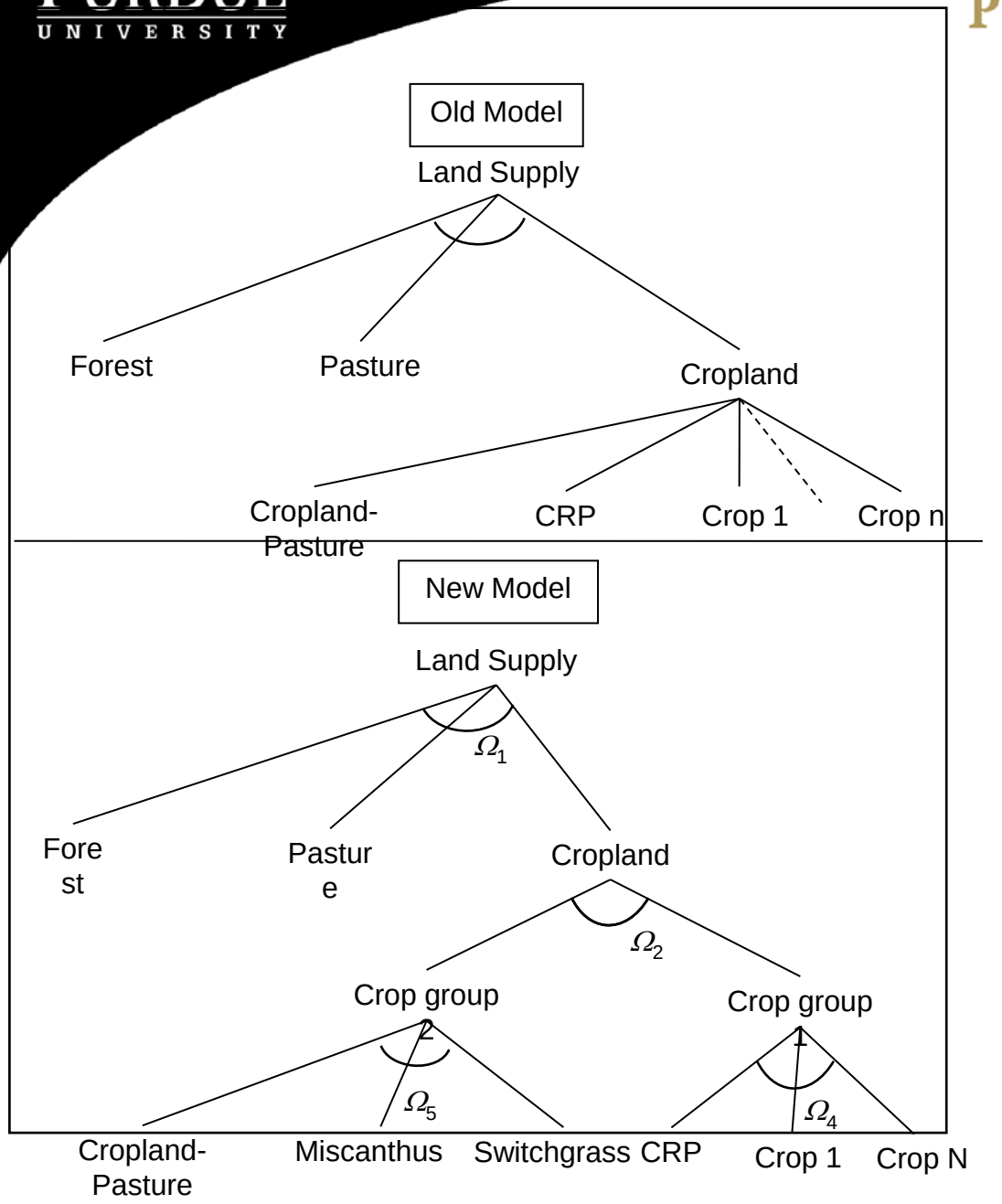
Household Demand Structure in the GTAP-BIO-ADVFUEL Model



pasture, miscanthus, and switchgrass = - 10



Land Cover and Land Use Activities in the GTAP-BIO-ADVFUEL Model

Add Greater Flexibility in Acreage Switching Among Crops

- In our previous work we and others had observed that GTAP does not seem to have as much acreage responsiveness as we experienced in the decade 2000-09.
- In this analysis, we asked the question of whether there is any difference in farmers reactions to crop price changes in the past decade and earlier periods.

Add Greater Flexibility in Acreage Switching Among Crops

- To answer this question we estimated acreage response to changes in soybean and corn returns per acre over different decades prior to 2000 and for 2000-2010. The following regression shows the results for the time period of 2000-2010:
  - Δ Harvested corn area (acres) = 1.388 + 0.084 Δ Corn revenue/acre(t-1) – 0.138 ΔSoybean revenue/acre(t-1),
  - The independent variable *t* values are 2.9 and 3.0 respectively, and the adjusted R^2 is 0.44.
- We did the same regressions for prior periods and found no significant relationship.

Add Greater Flexibility in Acreage Switching Among Crops

- As the literature suggests, in prior periods, government policy was a major driver, and now it is commodity prices and revenue.
- For these reasons, we increased the transformation elasticity that helps govern the response in acreage share to changes in commodity prices from 0.5 to 0.75.
- However, we are still experimenting with this parameter value to make sure it is the best representation of reality possible.

Endogenous Cropland Pasture Yield Change

- We received comments on our previous work suggesting that the increased use of land for biofuels would lead to investments in increased productivity as land rents increased.
- This led us to introduce an endogenous change in cropland pasture productivity as cropland pasture rent increases due to higher demand for the resource.
- This change in productivity is a function of the change in rent and a new elasticity parameter.

Scenarios Simulated

- An increase in corn ethanol production from its 2004 level (3.41 BG) to 15 BG, off of the 2004 database.
- An increase in production and consumption of Bio-Gasoline produced from corn stover by 6 BG (or 9.0 BG ethanol equivalent), off of 15 BG corn ethanol.
- An increase in production and consumption of Bio-Gasoline produced from miscanthus by 4.7 BG (or 7 BG ethanol equivalent), off of 15 BG corn ethanol.
- An increase in production and consumption of Bio-Gasoline produced from switchgrass by 4.7 BG (or 7 BG ethanol equivalent) on top of 15 BG corn ethanol,

Scenarios Simulated

- Increase in the production and consumption of ethanol from corn stover by 9 BG, on top of 15 BG corn ethanol
- Increase in the production and consumption and consumption of ethanol from miscanthus by 7 BG on top of 15 BG of corn ethanol.
- Increase in the production and consumption of ethanol from switchgrass by 7 BG on top of 15 BG of corn ethanol.

Preliminary Land Use Changes

		Land cover	US	EU	Brazil	Others	Total
(a)	15 BG ETH Off of 2004	Forest	-331	-80	42	144	-226
		Crop	971	126	82	899	2,078
		Pasture	-639	-46	-123	-1,043	-1,852
		Land cover	US	EU	Brazil	Others	Total
(b)	6 BG Stover Bio-Gasoline	Forest	8	2	0	47	56
		Crop	-13	-2	-2	-15	-32
		Pasture	5	0	2	-32	-24
		Land cover	US	EU	Brazil	Others	Total
(c)	4.7 BG Miscanthus Bio-Gasoline	Forest	-153	-16	8	24	-137
		Crop	106	25	15	173	319
		Pasture	47	-9	-23	-197	-183
		Land cover	US	EU	Brazil	Others	Total
(d)	4.7 BG Switchgrass Bio-Gasoline	Forest	-550	-45	20	-16	-590
		Crop	223	65	40	447	775
		Pasture	327	-20	-60	-431	-185

Preliminary Land Use Changes - Ethanol

		Land cover	US	EU	Brazil	Others	Total
(e)	9 BG Stover Ethanol	Forest	19	3	0	52	74
		Crop	-13	-4	-3	-25	-44
		Pasture	-6	1	3	-28	-30
		Land cover	US	EU	Brazil	Others	Total
(f)	7 BG Miscanthus Ethanol	Forest	-221	-21	11	26	-205
		Crop	134	32	20	222	408
		Pasture	88	-11	-31	-249	-202
		Land cover	US	EU	Brazil	Others	Total
(g)	7 BG Switchgrass Ethanol	Forest	-784	-61	28	-29	-845
		Crop	301	89	54	610	1,054
		Pasture	483	-28	-82	-581	-208

Land use changes

	Biofuel Case	Biofuel Produced (billion gallon)	New Cropland Needed (1000 ha.)	New Cropland Needed (ha./1000 gallons of biofuel)	New Cropland Needed (ha./1000 gallons of ethanol eq.)
(a)	Corn Ethanol	11.59	2078	0.18	0.18
(b)	Stover Bio-gasoline	6	-32	-0.005	-0.004
(c)	Miscanthus Bio-gasoline	4.7	319	0.07	0.05
(d)	Switchgrass Bio-gasoline	4.7	775	0.16	0.11
(e)	Stover Ethanol	9	-44	-0.005	-0.005
(f)	Miscanthus Ethanol	7	408	0.06	0.06
(g)	Switchgrass Ethanol	7	1054	0.15	0.15

Biofuels Covered

- US Corn ethanol
- US soybean biodiesel
- Brazilian ethanol

Sensitivity Analyses

- Sensitivity of land cover changes with respect to changes in the food demand induced by higher food prices due to biofuel production.
- Sensitivity of land cover changes with respect to yield-to-price elasticity.
- Sensitivity of land cover changes with respect to cropland transformation elasticity.
- Sensitivity of land cover changes with respect to endogenous productivity change for cropland pasture.

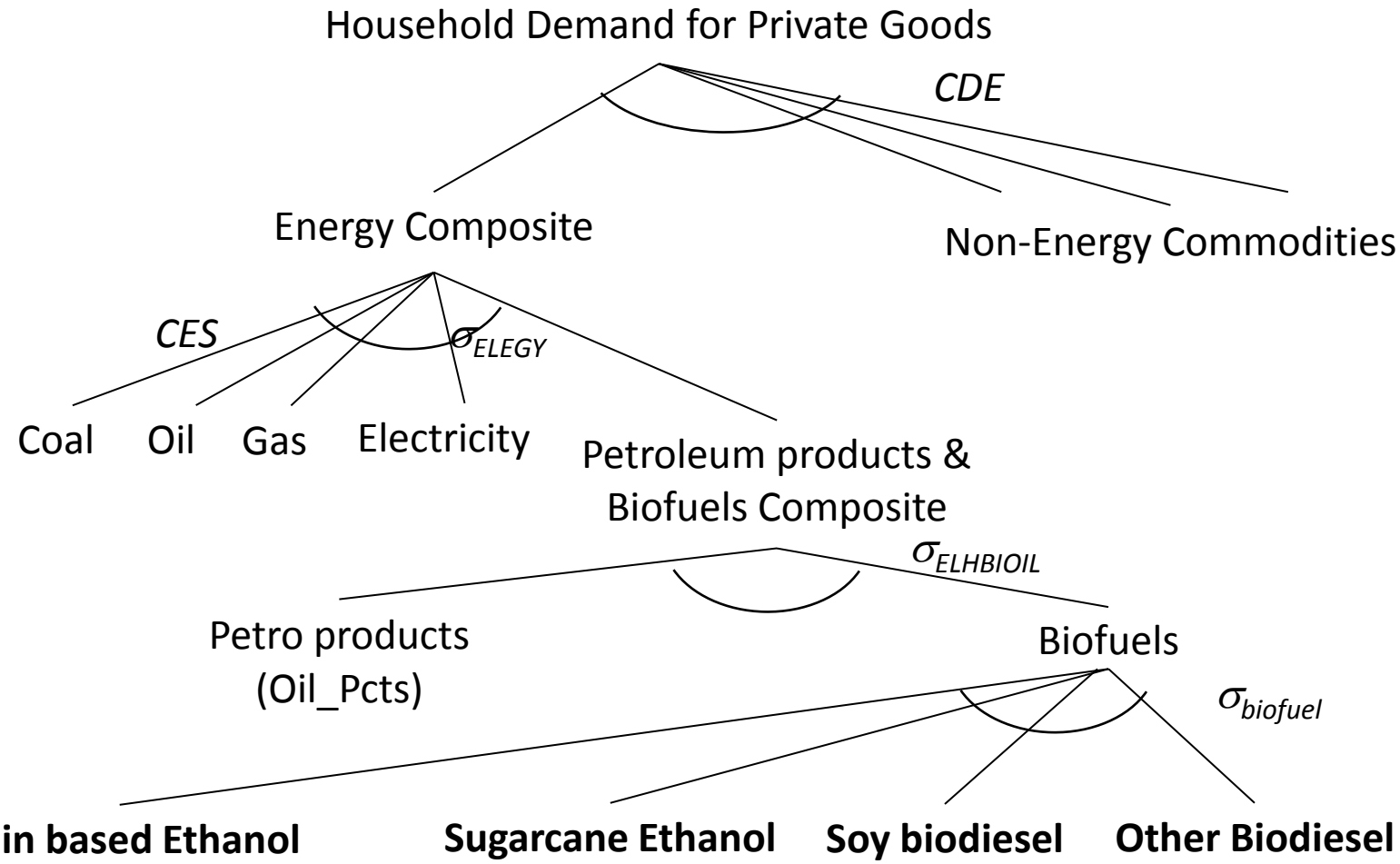
Model Modifications

- Updated energy elasticities,
- Improved treatment of DDGS and oilseed meals and oils,
  - Separation of soybean from other oilseeds,
  - Separation of soybean oil from other vegetable oils and fats,
- Separation of soybean biodiesel from other types of biodiesel.
- Modified model structure for livestock sector.

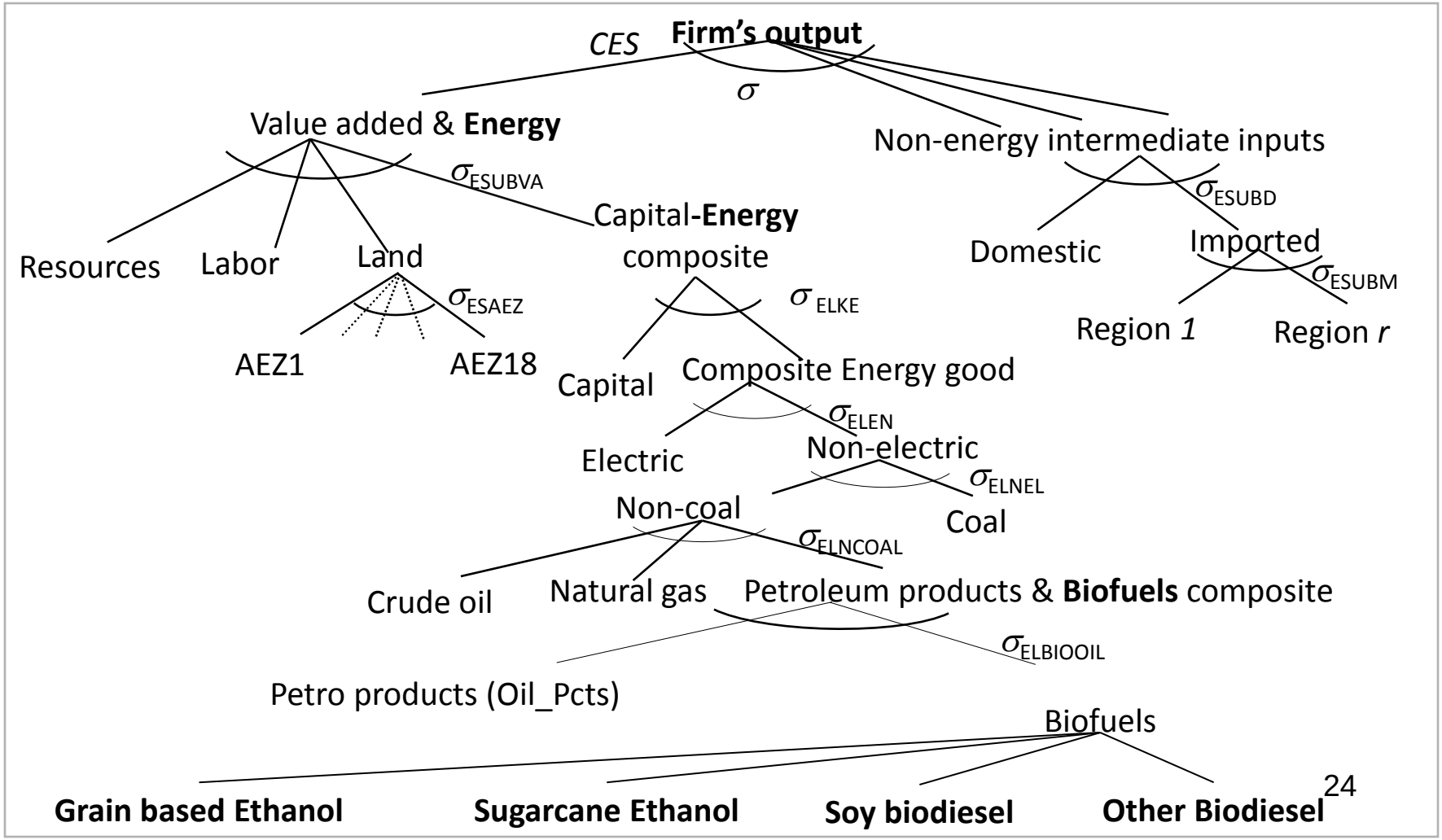
Model Modifications

- Revised land conversion factor for new cropland,
- Incorporate cropland pasture for US and Brazil and CRP for US,
- Endogenous yield adjustment for cropland pasture,
- Greater flexibility in cropland switching.
- Substitution among soybean oil and other vegetable oils and fats

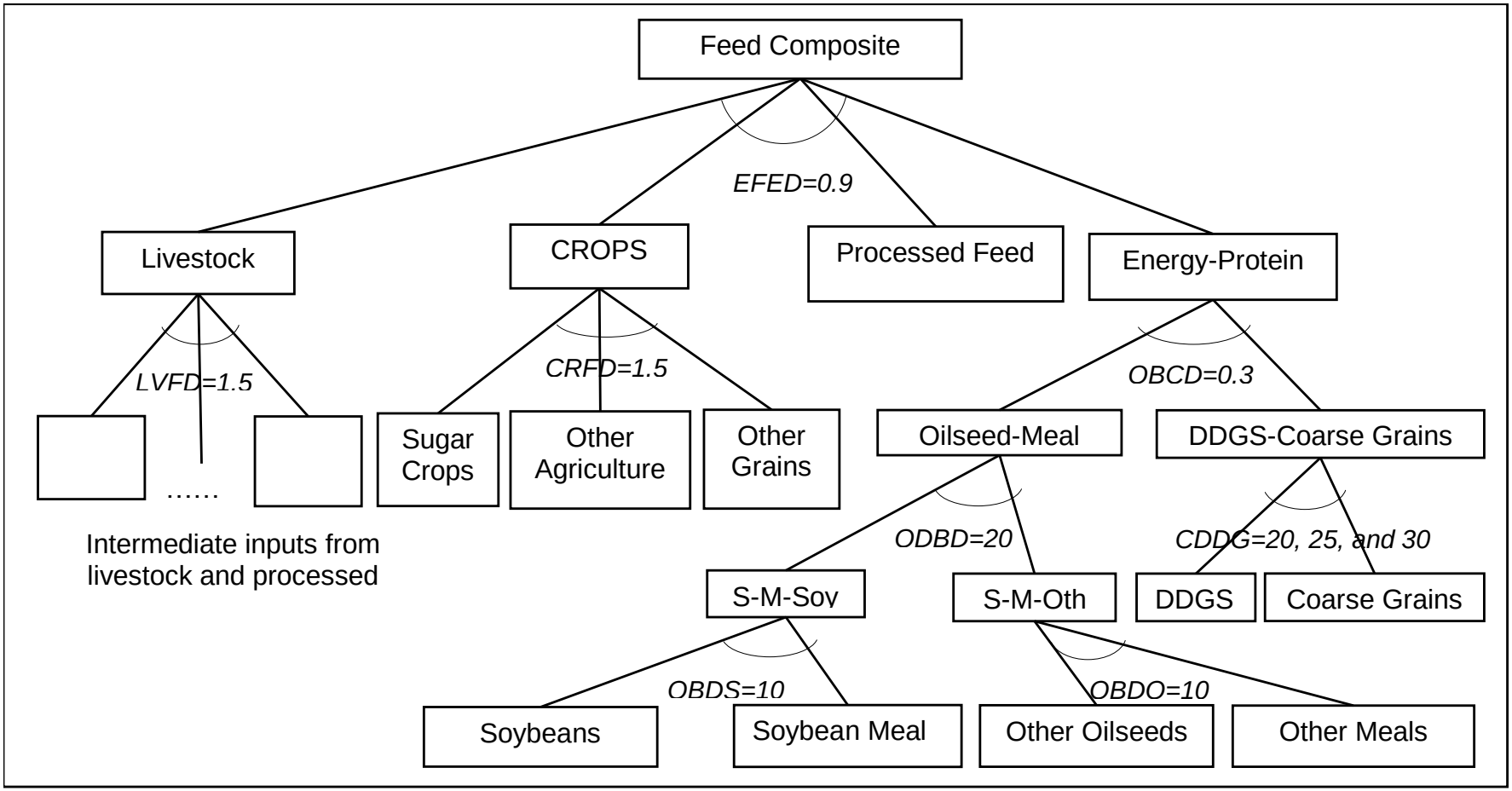
Household Demand Structure



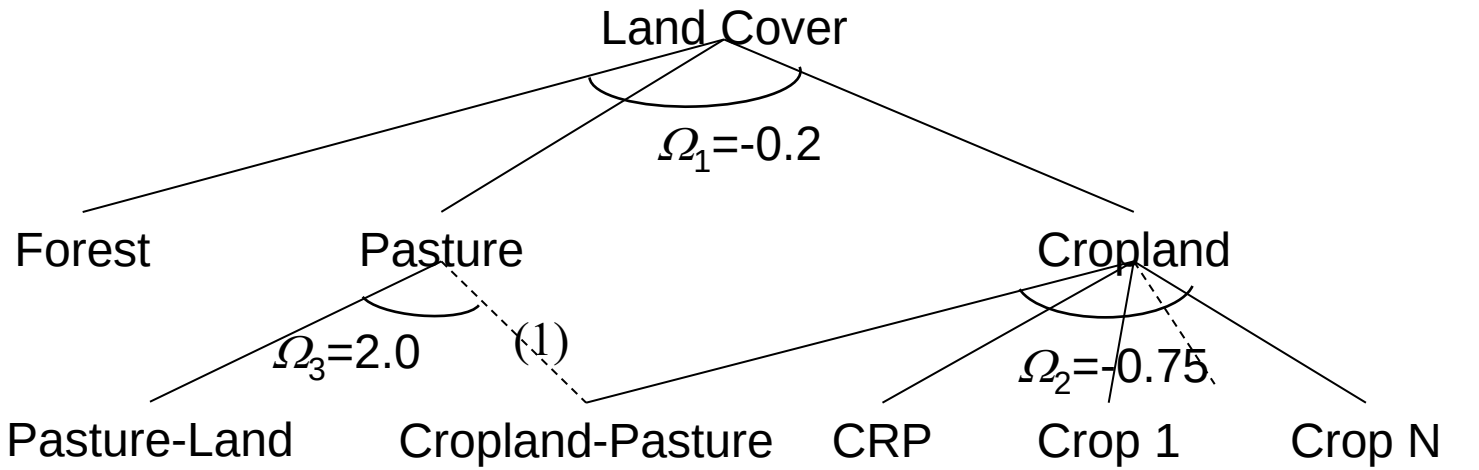
Firms Input Demand Structure



Nested Demand for Livestock Feed



Land Cover and Use Nesting



(1) In this land supply tree Ω_1 and Ω_2 are transformation elasticities and Ω_3 is the elasticity of substitution between pasture land and cropland pasture in the livestock industry

Endogenous Cropland Pasture Yield Change

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- This led us to introduce an endogenous change in cropland pasture productivity as cropland pasture rent increases due to higher demand for the resource.
- This change in productivity is a function of the change in rent and a new elasticity parameter.

Endogenous Cropland Pasture Yield Change

$$af_{pasture} = \propto \left[1 + \beta \left(\frac{A}{A+B}\right)\right] pf$$

- $af_{pasture}$ *:* Cropland pasture augmenting technical change,
- *A:* Area under dedicated energy crop (0 in this analysis),
- B: Area remaining in cropland pasture,
- *pf* : Percent change in the cropland pasture rent,
- *α:* Scalar yield elasticity (0.4),
- *β:* Scalar yield adjustment factor (0 in this analysis),
- The yield-to-price elasticity is set to zero for cropland pasture.

New Database Modifications

- Split harvested area and production of soybeans from other oilseeds,
- The *osd* sector is divided into two industries of *Soybeans* and *Other_Oilseeds*,
- The *vol* industry divided into two industries of *Vol_Soy* and *Vol_Oth* which prodcue:
  - Soybean oil and Soybean meal,
  - Other vegetable oils and non-soybean meals
- We incorporated two biodiesel industries of *Biod_Soy* and *Biod_Oth*.

Land Use Change Results

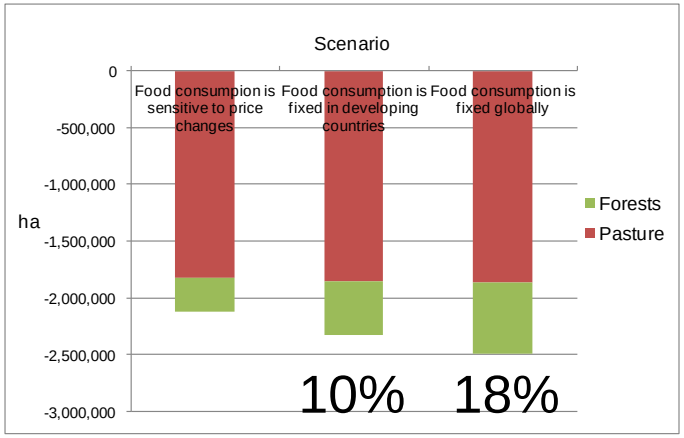
(ha/1000 gal. biofuel)

Biofuel	CARB 2009	Purdue 2010	Current Results	Results with CP
US corn ethanol	0.29	0.13 – 0.22	0.18	0.31
US soy biodiesel	0.63	0.94[a]	0.33	0.64
Brazilian sugarcane	0.55	-	0.16	0.39

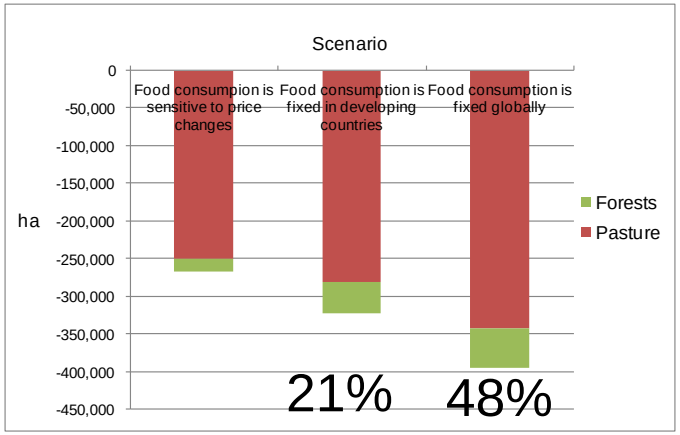
Complete details on land use change have been provided to CARB.

Food Consumption Sensitivity

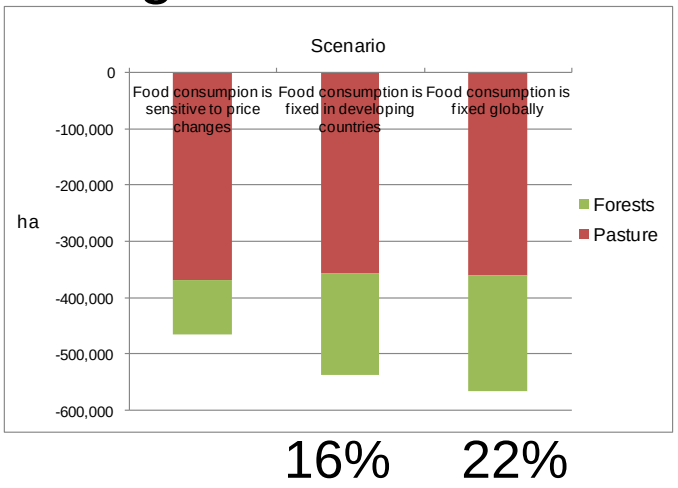
Corn ethanol



Soy biodiesel



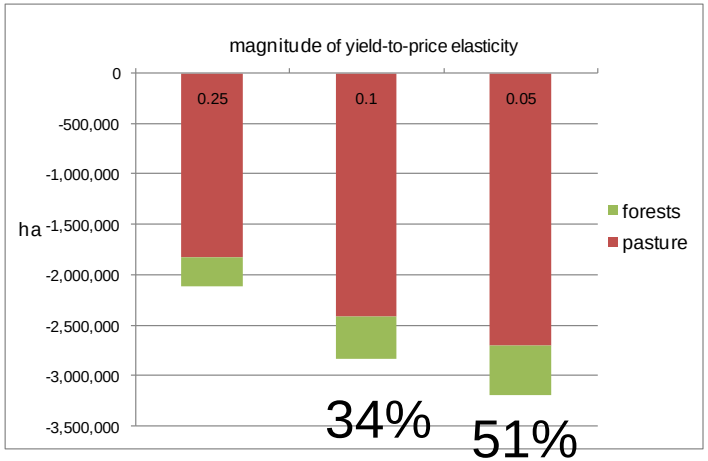
Sugarcane ethanol



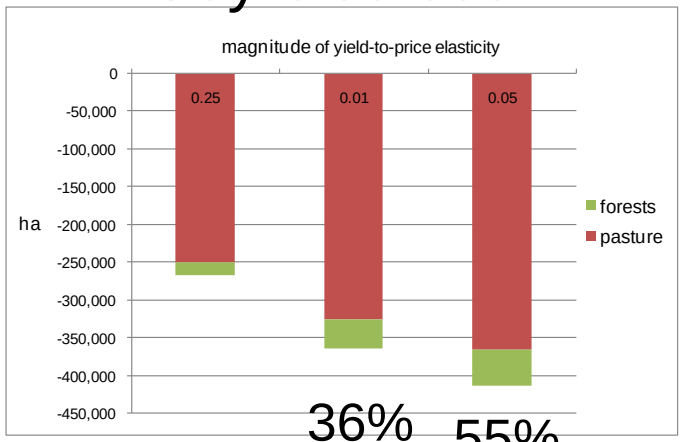
The food consumption sensitivity results indicate that the land cover change is somewhat sensitive to changes in the food consumption assumption.

Yield-to-price Elasticity Sensitivity

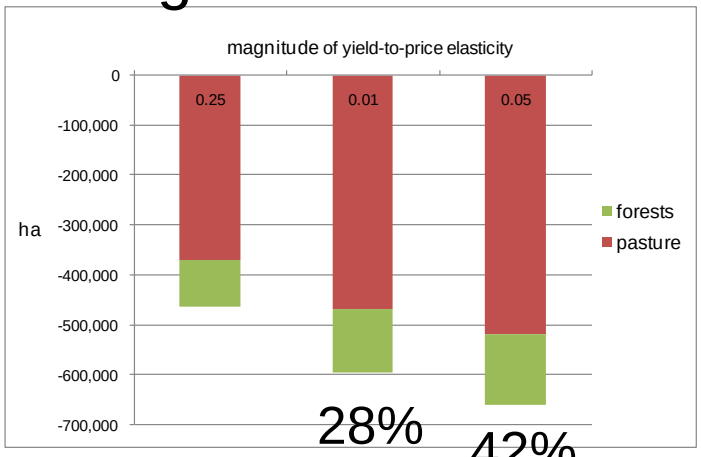
Corn ethanol



Soy biodiesel



Sugarcane ethanol



The results in all cases are sensitive to the value of the price-yield elasticity. Of the three, sugarcane is least sensitive, and soybean is the most sensitive.

Sensitivity on cropland transformation elasticity and cropland pasture endogenous technical change elasticity

Biofuel Case		Transformation Elasticity = -0.75			Transformation Elasticity = -0.5		
		forest	Cropland	pasture	forest	Cropland	Pasture
US corn ethanol	Area	-290,330	2,118,901	-1,828,303	-246,078	2,237,912	-1,991,761
	ha/1000 gall	-0.03	0.18	-0.16	-0.02	0.19	-0.17
US soy biodiesel	Area	-18,286	267,915	-249,803	-9,639	272,147	-262,557
	ha/1000 gall	-0.02	0.33	-0.31	-0.01	0.34	-0.32
Brazilian Sugarcane ethanol	Area	-95,315	465,295	-369,887	-36,457	543,158	-506,862
	ha/1000 gall	-0.03	0.16	-0.12	-0.01	0.18	-0.17

Biofuel Case		US=0.4 and Brazil=0.2			US=0.0 and Brazil=0.0		
		forest	Cropland	pasture	forest	Cropland	Pasture
US corn ethanol	Area	-290,330	2,118,901	-1,828,303	-550,067	2,011,577	-1,461,333
	ha/1000 gall	-0.03	0.18	-0.16	-0.05	0.17	-0.13
US soy biodiesel	Area	-18,286	267,915	-249,803	-62,022	247,766	-185,742
	ha/1000 gall	-0.02	0.33	-0.31	-0.08	0.31	-0.23
Brazilian Sugarcane ethanol	Area	-95,315	465,295	-369,887	-186,249	449,784	-263,459
	ha/1000 gall	-0.03	0.16	-0.12	-0.06	0.15	-0.09

Thank you!

Questions and Comments

For more information:

http://www.ces.purdue.edu/bioenergy

http://www.agecon.purdue.edu/directory/details.asp?username=wtyner