An Exploration of Certain Aspects of CARB's Approach to Modeling Indirect Land Use from Expanded Biodiesel Production

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Abstract

This report provides insight into four aspects of modeling indirect land use caused by expanded biofuels production. The report was motivated by the National Biodiesel Board's interest in better understanding how the California Air Resources Board (CARB) estimated an indirect land-use factor for soybean-based biodiesel of 66 gCO2e/MJ, which is more than three times greater than the direct emissions from the fuel. Four aspects of CARB's modeling approach were examined: (1) why CARB estimates that more U.S. forest than pasture will be converted to cropland; (2) whether CARB's predicted land-use changes are consistent with observed U.S. land-use changes in the past decade; (3) how CARB could account for double cropping; and (4) whether CARB's assumption that land brought into production has lower yields than land that was already in production. Results indicate that (1) much of the predicted U.S. forestland conversion is likely due to restrictions on cross-price elasticities imposed by use of the Constant Elasticity of Transformation supply function; (2) a stock of idled cropland could have accommodated the increase in U.S. cropland in 2007 and 2008; (3) the soybean yield elasticity with respect to price can be adjusted to account for double-cropped acres; and (4) there is no empirical support for the assumption that yields in Brazil on new land are lower than yields on old land. The analysis shows how much work needs to be done in this area if the models used to estimate indirect land use are to become widely accepted.

Keywords: CET supply function, double cropping, idle cropland, indirect land use.

AN EXPLORATION OF CERTAIN ASPECTS OF CARB'S APPROACH TO MODELING INDIRECT LAND USE FROM EXPANDED BIODIESEL PRODUCTION

Motivation and Background

In the middle of December, the California Air Resources Board (CARB) released their life cycle analysis of biodiesel (CARB 2009a). The CARB analysis concluded that greenhouse gas emissions from soybean-based biodiesel—from growing the crop to transporting the fuel to California—are 21.25 grams of carbon dioxide equivalent per megajoule (gCO_2e/MJ) of energy. CARB's earlier conclusion (CARB 2009b) that emissions from ultra-low-sulfur diesel refined from petroleum are 95.3 gCO_2e/MJ suggests that the replacement of petroleum diesel with biodiesel made from midwestern soybeans would lower emissions by a substantial amount and could meaningfully contribute to lowering the carbon content of California's transportation fuels. However, CARB's analysis also concluded that indirect land-use changes brought about by expansion of U.S. soybean acreage to meet higher demand for biodiesel would cause an additional 66 gCO_2e/MJ in emissions. Adding this to the direct emissions from biodiesel shows that biodiesel can contribute very little to lowering emissions from diesel use in California.

The model that California used to estimate the emissions from land-use changes is GTAP (Global Trade Analysis Project). This model is widely used to provide insights into the market impacts of changes in agricultural trade and commodity policy. Many users of GTAP[1] are quite knowledgeable about how the model works and how model results should be interpreted. This knowledge, however, does not extend to people who make transportation fuel and who are affected by CARB's analysis.

Biodiesel producers are directly affected by CARB's findings because if their estimates are adopted by the state, this would limit the demand for biodiesel in the largest U.S. fuel market. The national trade association of the biodiesel industry is the National

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[1] See Birur, Hertel, and Tyner 2008 for a description of GTAP and Hertel et al. 2010 for a description of the CARB analysis for corn ethanol.

Biodiesel Board (NBB). NBB staff were interested in commenting on the CARB report but did not have an adequate technical background to understand how CARB estimated the emissions associated with land-use changes or whether the modeling approaches taken by CARB were reasonable and reliable. Comments from NBB on the CARB analysis needed to be submitted within 30 days.

Staff of the NBB approached the Center for Agricultural and Rural Development (CARD) at Iowa State University with an offer to support research that would enable them to better comment on CARB's analysis.[2] A series of short, quick-turnaround reports resulted from our research effort. This staff report is a compilation of the individual reports delivered to NBB. The objectives of these reports were to determine (1) why CARB estimates that forestland would be converted to cropland at a higher rate than pastureland is converted to cropland in response to expanded biodiesel; (2) whether land-use changes in recent years are consistent with the basic modeling assumption used by CARB that there is no idle cropland available for expansion; (3) whether CARB's analysis can be modified to account for the importance of double cropping; and (4) whether land brought into production is less productive than existing land. The following four sections of this report contain the analysis and findings of the research completed to meet each of these objectives.

Responsiveness of Land Conversion

It is common knowledge among those who follow the debates about indirect land use that CARB uses GTAP to estimate indirect land use. It is also somewhat well known that GTAP is a computable general equilibrium model, and that it allocates land within a region to maximize total returns to land. But a relatively small group of people understands exactly how GTAP does this land allocation and what restrictions/assumptions are made to enable an equilibrium to be found. This section provides a bit of insight into this process by focusing on the function that utilizes a key parameter in CARB's analysis.

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[2] CARD researchers have worked extensively on indirect land-use modeling for the Environmental Protection Agency since 2008.

GTAP allocates land among crops, pasture, and forest using a function called the constant elasticity of transformation (CET) supply function. This supply transforms a single input (aggregate land) into three outputs (land allocated to crops, forest, and pasture). GTAP uses this transformation function to allocate land such that total returns from land are maximized. The CET function itself depends only on the share of total returns for each land type and a single parameter, σ, which is referred to as the elasticity of land transformation. This function is used because it is parsimonious and because it imposes the necessary convexity that allows a solution to the maximization problem to be found. However, the convenience of this function imposes some restrictions that may be important in predicting how much pasture and forestland is converted in response to crop price increases caused by biofuels expansion.

Following the notation on page 4 of Ahmed, Hertel, and Lubowski (2008), the cross-price elasticity of the supply of forestland in response to a crop price increase equals $\varepsilon_{forest,\,crop} = \theta_{crop}\sigma$ where θ_{crop} is the share of revenue from crops. The cross-price elasticity of pastureland in response to a crop price increase is $\varepsilon_{pasture,\,crop} = \theta_{crop}\sigma = \varepsilon_{forest,\,crop}$. This means that a 10% increase in crop prices will result in the same percentage change in pasture and forestland.[3] This equality of these two cross-price elasticities is a restriction imposed by the CET supply function having so few parameters. A more general function with more parameters would not impose this restriction at the cost of added computational complexity.

Homogeneity of supply[4] means that the own-price elasticity equals (in absolute value) the sum of the cross-price elasticities so that the own-price elasticity of pasture, forest, and crop in GTAP differ only by the share of revenue:

$$\varepsilon_{pasture,\,pasture} = -\sigma(1-\theta_{pasture})$$

$$\varepsilon_{forest,forest} = -\sigma(1-\theta_{forest})$$

$$\varepsilon_{crop,crop} = -\sigma(1-\theta_{crop})\,.$$

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[3] The equilibrium solution will not be exactly the same percentage change because the own-supply elasticities of forest and pasture will differ and the demand elasticities for forest products will differ from pasture products.

[4] Supply homogeneity means that if you double all prices, supply will not change.

The central value of σ in CARB's biodiesel analysis is -0.2, which is equal to the revenue-share-weighted average of the estimated individual land-cover CET parameters (discussed below) after five years.

Page 5 of Ahmed, Hertel, and Lubowski reports revenue share values of 0.7489 for crops, 0.0975 for pasture, and 0.1023 for forest. This means that the GTAP own-return elasticities of supply are 0.05, 0.18, and 0.18 for crops, pasture, and forest respectively. One cost of using the CET function to allocate land is that the own-return elasticities for pasture and forest are significantly different than what Ahmed, Hertel, and Lubowski estimate them to be. Their estimates are derived from analysis of plot-level National Resources Inventory (NRI) data from 1982 to 1996 conducted by Lubowski (2002) and Lubowski, Plantinga, and Stavins (2006). Ahmed, Hertel, and Lubowski estimate that the own-price elasticities at five years are approximately 0.045, 0.22, and 0.005 for crops, pasture, and forest, respectively.[5] Thus the GTAP own-price elasticities for crops and pasture are roughly equal to the empirically based own-price elasticities. But the forest elasticity in GTAP is 36 times higher than the estimated value.

There is a one-to-one correspondence between an own-price elasticity and a CET function parameter given the crop share, as illustrated above. The estimated CET parameter values for each type of land cover can be found in Figure 3 of Ahmed, Hertel, and Lubowski. These values are approximately -0.006 for forest, -0.26 for pasture, and -.25 for crops. The difference between the CARB central value of -0.2 and the elasticity of land transformation for forest that is consistent with the estimated value from Figure 3 is particularly important when considering the response of forestland to higher crop prices.

As previously stated, GTAP imposes the homogeneity condition that the own-price elasticity equals the absolute value of the sum of the cross-price elasticities. Because both cross-price elasticities are negative (a higher price of crops leads to less forestland) we know that their value must be between zero and the value of the own-price elasticity. Using a forest own-price elasticity of 0.18 allows the cross-price elasticities to be between 0 and -0.18. For example, if the cross-price elasticity of forest with respect to

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[5] These estimates were obtained from Figure 2 of Ahmed, Hertel, and Lubowski. The approximation of the forest elasticity was difficult because the five-year value was so close to zero.

pasture equals -0.08, then the cross-price elasticity of forest with respect to crops equals -0.1.[6] If GTAP had instead used 0.005 as the own-price elasticity of forests, then this implies that the cross-price elasticity of forestland with respect to crop prices would be limited to between 0 and -0.005.

The most important factor affecting the magnitude of the change in greenhouse gas emissions from land-use changes is the response of forestland to an increase in crop prices. Thus, use of the GTAP own-price elasticity of 0.18 instead of the empirically estimated own-price elasticity of forests of 0.005 results in dramatically higher greenhouse gas emissions. The GTAP cross-price elasticity of forest with respect to crop price equals

$$\varepsilon_{forest,\,crop} = \theta_{crop}\sigma = -0.7489 * 0.2 = -0.15.$$

This elasticity is 30 times higher than the maximum cross-price elasticity that would be possible if the empirically estimated forest own-price elasticity was used in the analysis.

The GTAP cross-price elasticity of pasture with respect to crops is also equal to -0.15, which may be close to the value that is consistent with the empirical estimates. This suggests that a model that used empirically based own- and cross-price elasticities for forest, pasture, and crops would have pastureland being at least 30 times more responsive to crop prices than forestland on a five-year horizon. The ratio of responsiveness would be similar for longer time periods, given the very low own-return elasticities for forest shown in Figure 2 of Ahmed, Hertel, and Lubowski.

Of course, this mismatch between what GTAP imposes on this cross-price elasticity and what seems to be implied by the estimates from Lubowski and Lubowski, Plantinga, and Stavins is not important if their estimates are wrong, and the actual elasticity of forestland is close to 0.18. Hertel et al. (2008) used Choi's (2004) estimated elasticity of forestland with respect to price of 0.25 to calibrate how forestland will respond to increased incentives to grow trees to mitigate atmospheric greenhouse gas concentrations. If this elasticity is correct then the GTAP restriction would not be important.

Both Choi and Lubowksi use NRI data to estimate how land use will change if the returns to forestland change. It may seem surprising that they come up with such a large

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[6] The share of revenue in Ahmed, Hertel, and Lubowski do not sum to one, which implies that "other" land use must be equal to one minus the sum of share to forest, crops, and pasture. The other land use is ignored in this explanation.

difference in their estimates. One possible explanation of their differences is straightforward. Lubowski uses NRI data to track how individual NRI points (which are representative of nearby land use) change over time. His supply elasticity is best interpreted as the response of a particular piece of land to changes in returns to forest relative to pasture and crops. His finding that there is very little response over a 5-, 10-, or 15-year period is consistent with the notion that forestland tends to stay as forestland in the short to medium term. Choi's analysis does not track individual NRI points. Rather, he is trying to explain why some counties have a high share of cropland relative to forestland and why other counties have a low share of cropland relative to forestland. He explains differences across counties by calculating the returns to crops and the returns to forest. Not surprisingly, he finds that counties where crop returns are highest have the highest amount of cropland. Put another way, Choi finds that counties that have land that is most suited for growing crops have the most cropland. Choi uses multiple years of data, but even if land use did not change over time in his sample, Choi would still find that counties with higher crop returns had more land in crops.

Given enough time and a change in the returns to crops relative to forest, then Lubowski's inelastic supply response would result in a change in long-run equilibrium land use of the type explained by Choi's analysis. That is, Choi's results are best interpreted as long-run equilibrium results because they explain why land that is forested today is not cropped.

CARB seems to have in mind a five-year elasticity of land-use change rather than a 50-year (long-run) elasticity. Evidence for this is that their central value of the elasticity of land transformation equals -0.2, which is the value of the parameter when the weighted average of the land-type specific parameters after five years are taken. Thus, use of the short-run (five-year) Lubowski elasticity estimates, rather than the long-run Choi estimates, seems appropriate.

If there is a wide variation between the GTAP-restricted and actual own-price elasticities of forest cover, then the direct GTAP output will overstate greenhouse gas emissions related to replacement for forestland with cropland. Unless the CET supply function can be replaced with a more flexible functional form that can accommodate a wider variation in own-price elasticities, some other mechanism should be used to better reflect actual own-price elasticities.

An ad hoc approach could take the total amount of pasture and forestland that GTAP converts and reallocate it between pasture and forest such that the percentage change in pasture is some multiple of the percentage change in forestland. For example, suppose GTAP predicts that U.S. crop acreage expands by 100,000 ha with 45,000 ha coming from forest and 55,000 ha coming from pasture. These estimates would be consistent with -0.15 cross-price elasticities in GTAP. An allocation of pasture and forestland that is more consistent with the Lubowski elasticities would be 95,000 ha of pasture and 5,000 ha of forest. This would be an ad hoc approach because these ratios would not account for the likely increase in the returns to pasture because of the greater loss of pasture. This hike in returns would, in turn, limit the amount of pasture that would be converted. So, instead, perhaps lowering the ratio of responsiveness from 30 to 1 to 10 to 1 would be more consistent with a model that uses the empirically estimated cross-price elasticities. This might result in 90,000 ha of pasture and 10,000 ha of forest. The magnitude of these changes suggests that making forestland less responsive to crop prices than pasture would result in major reductions in the amount of forestland converted to cropland. This would dramatically reduce estimated greenhouse gas emissions from land-use changes in response to expansion of biodiesel.

Consistency of Recent Land-Use Changes in the United States with CARB Estimates

The CARB biodiesel analysis (CARD 2010) indicates that between 0.13 and 0.23 million hectares (0.321 and 0.568 million acres) of U.S. land will be converted to cropland depending on the assumptions of the different scenarios. Averaging across scenarios, 0.17 million hectares of land could be brought into agricultural production. The results indicate that between 53% and 69% of the total expansion of U.S. cropland would occur by converting forestland (see Table 1) with the other 31% to 47% coming from pastureland. This section presents data on U.S. cropland changes in the last 15 years to see how well this model prediction accords with historical trends.

TABLE 1. Land-use changes in CARB's biodiesel analysis

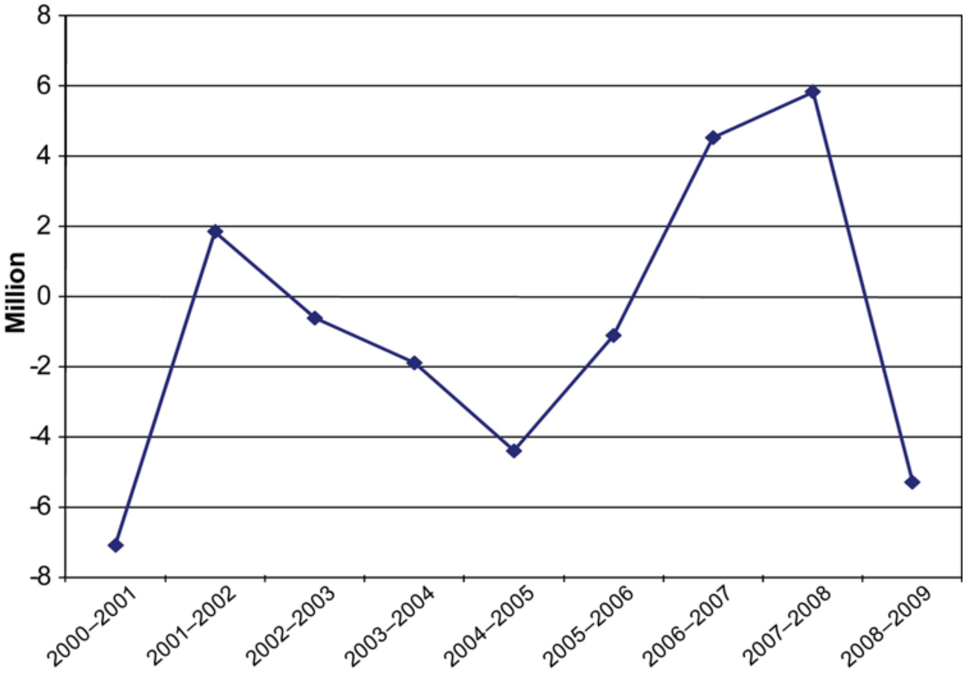
	CARB Scenario							
	A	B	C	D	E	F	G	Mean
U.S. land converted (million ha)	0.19	0.13	0.23	0.22	0.13	0.16	0.15	0.17
U.S. forest land (million ha)	0.12	0.08	0.13	0.12	0.09	0.09	0.08	0.1
U.S. pasture land (million ha)	0.07	0.05	0.10	0.10	0.04	0.07	0.07	0.07
% of forest on total converted	63%	62%	57%	55%	69%	56%	53%	59%

Source: CARB 2010.

To put the Table 1 estimates of land-use changes into perspective, Figure 1 shows the annual changes in U.S. crop acreage since 2000. The smallest change in acreage is the change from 2002 to 2003 at 0.6 million acres. Thus CARB's estimated changes are quite small relative to the acreage changes that we have actually observed in recent years.

It is useful to see if the changes in cropland shown in Figure 1 are associated with changes in pasture and forestland because CARB's GTAP analysis allocates land between crops, forests, and pasture to maximize total returns. We do not have annual data on forestland, but we do have data on hay land (pasture) and Conservation Reserve Program (CRP) land. Figure 2 compares the annual changes in CRP and pastureland to the changes in cropland shown in Figure 1. Between 2000 and 2001 the sharp drop in cropland corresponds to an increase in pasture and CRP land. And the sharp increase in cropland in 2007 and 2008 corresponds to a decrease in CRP land in 2008 and 2009, although both CRP and crop acres decreased significantly in 2009. But what is notable about Figure 2 is the long-term stability of hay land. And CRP acres have been stable as well with the exception of the significant declines in 2008 and 2009, when increased crop prices led to farmers deciding not to renew their CRP contracts.

The data in Figure 2 suggest that there is some trade-off between cropland and land enrolled in CRP and hay land, but the magnitude of the changes in cropland are much larger than the changes in either CRP or hay land. Because total land in the United States does not change, what land-use category is changing along with cropland? Because



Source: FAPRI Agricultural Outlook.

FIGURE 1. Annual changes in U.S. crop acreage for the 13 principal field crops

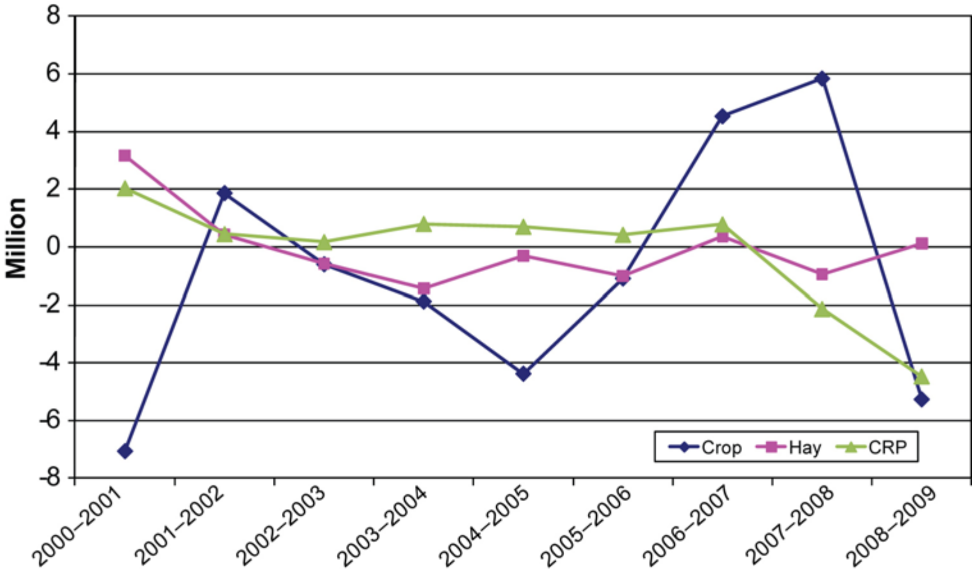


FIGURE 2. Annual changes in U.S. land devoted to crop, CRP, and hay

CARB allocates acreage between crops, pasture, forest, and other (typically industrial land), the answer from CARB's modeling perspective is that one of these categories must be increasing or decreasing. However, before taking land from one of these categories, an accounting for changes in double-cropped acreage needs to be made.

Figure 3 overlays the annual change in U.S. double-cropped acres on the change in cropped acres. As shown, the large expansion of crop acres in 2007 and 2008 were partly accomplished by increasing double-cropped acres. The correlation coefficient between the change in double-cropped acres and the change in crop acres over this time period is 0.8. This suggests that the first adjustment that should be made in accounting for how the U.S. expands or contracts crop acreage is to subtract double-cropped acreage from total crop acreage. Figure 3 shows that the annual change in crop acreage is significantly reduced by such a subtraction. The standard deviation of annual cropland changes from 2001 to 2009 drops from 4.37 to 3.32 million acres by this subtraction.

The question then becomes whether changes in actual planted acreage adjusted for double cropping are accounted for by changes in pasture and CRP land. A scatter plot of the annual changes (with the annual change in crop acres shown on the horizontal axis) is shown in Figure 4. If there exists a strong negative relationship between pastureland and cropland, then most of the points should be in the southeast and northwest quadrants. However, only three of the nine points appear in this quadrant, with the two most prominent changes occurring in 2001 and 2008.

One conclusion that can be drawn from Figure 4 is that the annual fluctuations in crop acreage are not highly correlated with annual fluctuations in pastureland. What this suggests is that some other land use is absorbing the annual changes. This could be either changes in forest cover, urban land, or it could be that idle cropland moves in and out of production as economic conditions warrant.

Insight into whether the land-use changes that we have seen since 2000 are consistent with a stock of idle cropland can be obtained by looking at Figure 5, which shows the annual flux of cropland not accounted for by double-cropped acres, CRP land, or hay land. A positive number means that land is flowing out of cropland and potentially into idle cropland. A negative number means a potential reduction in idle cropland. As

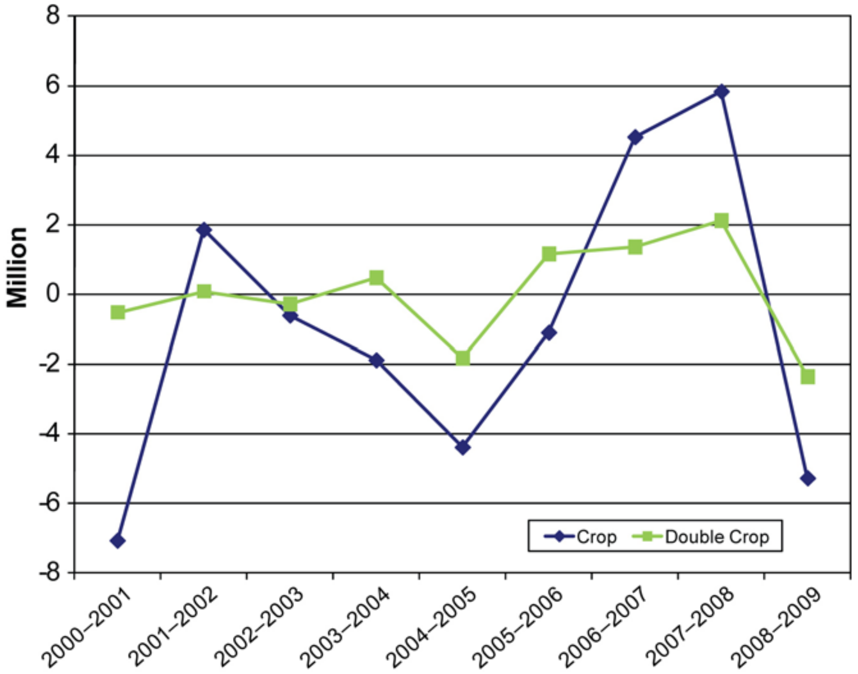


FIGURE 3. Accounting for changes in double-cropped acres

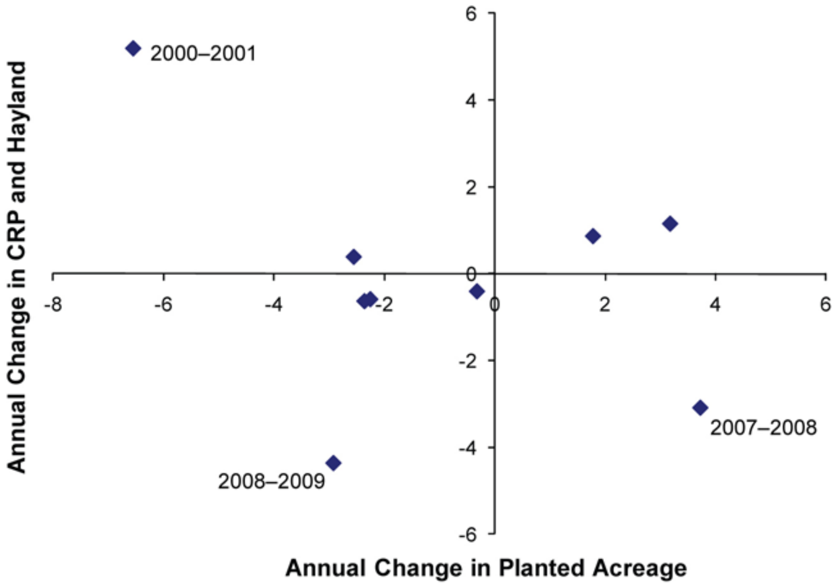


FIGURE 4. Relationship between cropland changes and pasture changes

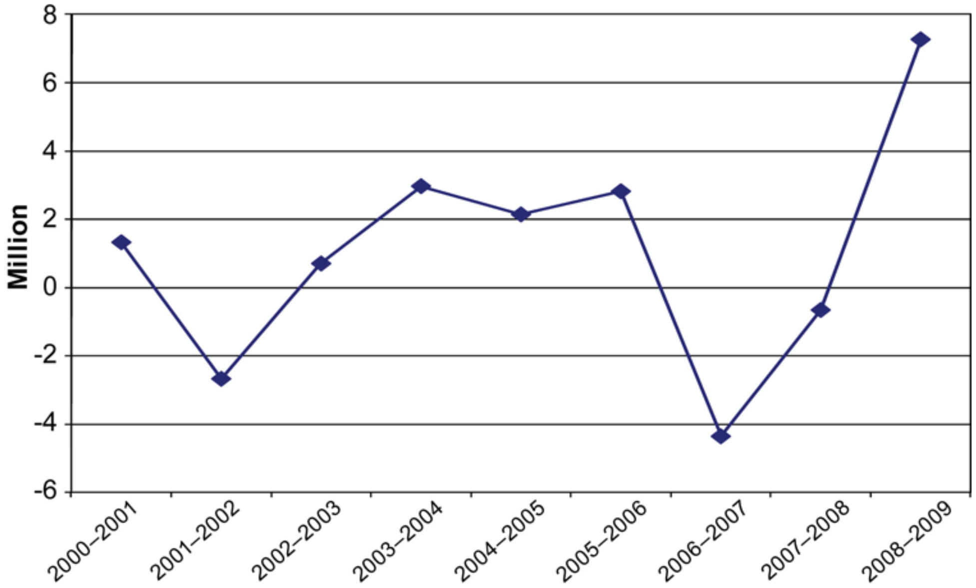


FIGURE 5. Potential flux of idle cropland

shown, if Figure 5 does measure flux in idle cropland, then 2002, 2007, and 2008 reduced the stock of idle land, and the remaining years increased the stock. One question that is raised, in this limited time period, is whether there was enough flow of land into the stock of idle cropland to offset the flows out of the stock. This question is answered by looking at the level of the stock of idle cropland (Figure 6), which is simply the sum of the Figure 5 flux. As shown, the deficit in crop acres (not accounted for by changes in pasture, CRP, or double cropping) in 2002 and 2003 were greater than the reduction in crop acres in 2001. Thus, either the stock of idle cropland in 2000 was greater than zero, or some other category of land needed to be converted into cropland. The increase in crop acres in 2007 and 2008 could have been accommodated by the reduction in crop acres in 2004, 2005, and 2006. And the 2009 reduction in crop acres has seemingly rebuilt the stock of potentially idle land. Whether the deficits in the stock of idle land in 2002 and 2003 could have been accommodated by an earlier buildup in idle land is revealed by Figure 6, which treats the stock of idle cropland as being zero in 1996, instead of in 2000. As shown, there was a large reduction in cropland in 1998 that could have created enough of a reserve of idle land to accommodate the 2002 and 2003 deficits.

Figure 7 shows that it was possible to meet all demands for cropland out of land that was previously idled. Of course, this assumes that the land that moved out of crops

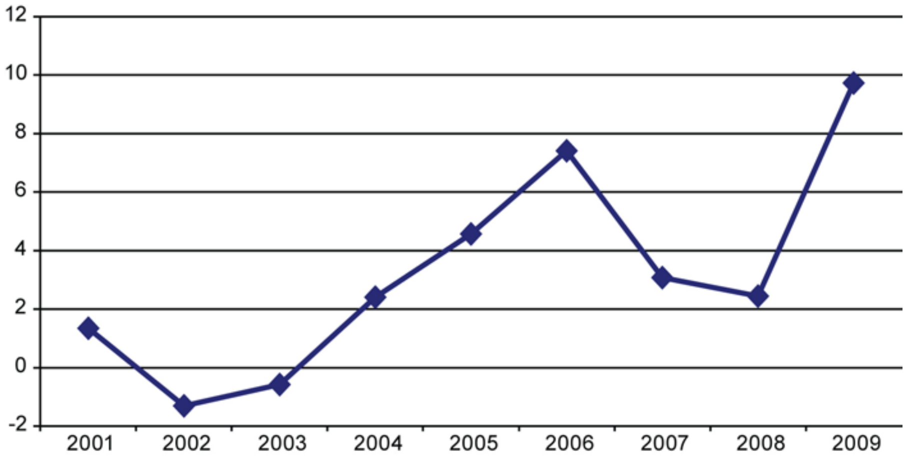


FIGURE 6. Potential stock of idle cropland assuming no idle land in 2000

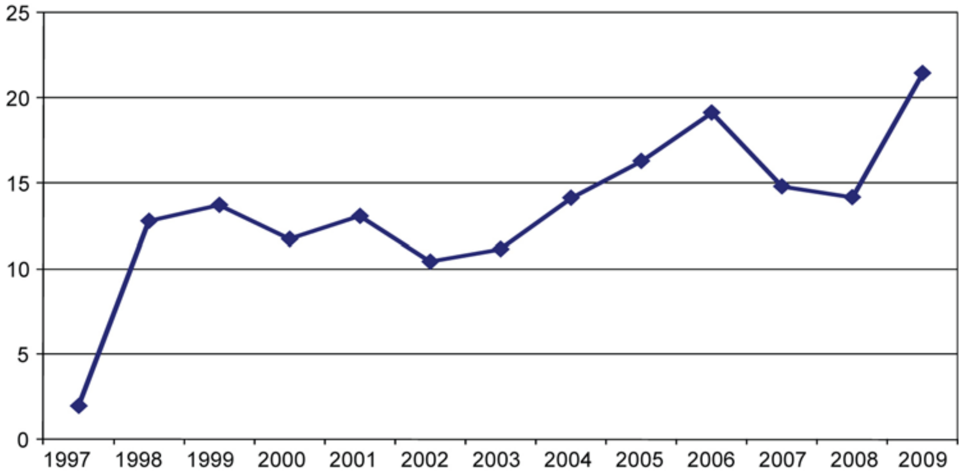


FIGURE 7. Potential stock of idle cropland assuming no idle land in 1996

(and that did not move into pasture or CRP) did not move to urban land or forests. If a large portion of the land attributed to idle cropland in Figure 7 became forest or if houses were built on it, then it would not have been available to meet the demands for cropland in 2007 and 2008.

Recent trends for U.S. land use as measured by the NRI are shown in Table 2. The NRI provides nationally consistent data at several points in time for the 1982-2003 period. Total land covered in Table 2 is constant (at 1.938 billion acres) for all the NRI survey years, and thus the reallocation of land across uses can be assessed. The data

TABLE 2. Total surface area by land cover/use by year

Year	Cropland	CRP Land	Pastureland	Rangeland	Forestland	Other Rural Land	Developed Land	Water Areas	Federal Land
					(million acres)				
1982	419.9	0	131.1	415.5	402.4	48.2	72.9	48.6	399.1
1992	381.3	34	125.2	406.8	403.6	49.4	86.5	49.4	401.5
1997	376.4	32.7	119.5	404.9	404.7	50.4	97.6	49.9	401.7
2001	369.5	31.8	119.2	404.9	404.8	50.1	105.2	50.3	401.9
2003	367.9	31.5	117	405.1	405.6	50.2	108.1	50.4	401.9
Changes in consecutive reports									
1992-1982	-38.6	34	-5.9	-8.7	1.2	1.2	13.6	0.8	2.4
1997-1992	-4.9	-1.3	-5.7	-1.9	1.1	1	11.1	0.5	0.2
2001-1997	-6.9	-0.9	-0.3	0	0.1	-0.3	7.6	0.4	0.2
2003-2001	-1.6	-0.3	-2.2	0.2	0.8	0.1	2.9	0.1	0
Changes by year for different NRI intervals									
1992-1982	-3.86	3.40	-0.59	-0.87	0.12	0.12	1.36	0.08	0.24
1997-1992	-0.98	-0.26	-1.14	-0.38	0.22	0.20	2.22	0.10	0.04
2001-1997	-1.72	-0.23	-0.07	0.00	0.03	-0.07	1.90	0.10	0.05
2003-2001	-0.80	-0.15	-1.10	0.10	0.40	0.05	1.45	0.05	0.00
Average[a]	-1.17	-0.21	-0.77	-0.09	0.22	0.06	1.86	0.08	0.03

Source: Calculated by authors based on the 2003 Annual NRI report.

[a] Average is since 1992, to avoid confounding effect of CRP introduced in the first interval.

indicate that forest and developed area have been consistently expanding over the 20-year period covered. At the same time, pasture and crop areas have declined over time. These observations have been made in the literature. According to Alig, Kline, and Lichtenstein (2004), while in recent decades forests have been the largest source of land converted to developed uses, these losses are more than offset by displacement of cropland and pastures (by forests). According to the authors, "movement of land between forestry and agriculture in the last two decades has resulted in net gains to forestry that have offset forest conversion to urban and developed uses in area terms" (p. 229).

Hence, history since 1982 indicates forests advancing over cropland. This suggests that at least some portion of the loss of cropland shown in Figure 7 could be accounted for by an increase in forestland. However, note that the rate of increase in forestland seems to have decreased after 1997, so the magnitude of the change in cropland in Figure 7 is not consistent with all of it being converted to forest. Note also that the increase in urban land from 1997 to 2003 is about equal to the decrease in cropland over the same period, and that the NRI decrease in cropland is much less than the Figure 7 decrease in cropland. Thus it seems likely that at least that some portion of the Figure 7 cropland was urbanized and that most of the remainder stayed as cropland, as reported in the NRI, but was not planted.

This examination of land-use changes shows that if CARB wants its analysis to reflect the actual land-use patterns seen in the last two decades, then the GTAP model, which allocates land between crops, pasture, and forests, should be altered to include an idle cropland category. This would reflect the fact that there is a relatively large amount of cropland that moves in an out of crops as economic conditions dictate. This change would better reflect the reality of cropland changes since 1997 and it would result in a more accurate estimate of the greenhouse gas emissions from U.S. land-use changes because conversion of idle cropland to active cropland incurs few emissions. Of course, the data requirements of making such a change are not trivial, as this brief examination of the data suggests. The feasibility of implementing such a change in modeling structure outside the U.S. and perhaps Europe presents an even larger challenge. But this is the type of data that is needed to facilitate the type of analysis that is required to accurately estimate actual land-use changes from expanded biofuels.

The feasibility of altering the GTAP model to add an additional land category that is a close substitute to cropland is not known. An ad hoc measure that could be employed would be to assign to idle cropland a portion of the total amount of land that GTAP projects is converted from pasture and forest. This would necessarily be outside the model, so the assignment would not be reflected in equilibrium returns to forest and pasture. But the final greenhouse gas calculations would better reflect the existence of a significant amount of idle cropland.

Is Converted Land Less Productive than Current Land?

One of the crucial assumptions for the CARB calculation of the land-use change carbon intensity of biofuels is the "elasticity of crop yields with respect to area expansion." This elasticity attempts to capture differences in yields from newly converted lands and established areas of the same crop. The basic premise of CARB is that "all of the land that is well-suited to crop production has already been converted to agricultural uses, yields on newly converted lands are almost always lower than corresponding yields on existing cropland." (CARB 2010, p. 3). For the CARB analysis, this input for the GTAP model was selected in the range of 0.5 to 0.75. Sensitivity analysis indicates that a change from 0.5 to 0.75 results in a 38% reduction in land-use change intensity. Of the seven scenarios run for GTAP, four placed the crop yield elasticity on the lower end of the selected range, two selected the upper end (0.75), and the remainder used a value close to the center of the range (0.66). Given the prevalence of scenarios on the lower end of the range, the average across scenarios is 0.57, increasing the calculated carbon intensity of biodiesel. If the average elasticity across scenarios was set closer to the average of the assumed range (i.e., 0.625) then carbon intensities would have decreased by an average of 8.6%.

More fundamentally, what is the evidence point that "all of the land that is well-suited to crop production has already been converted to agricultural uses"? This assumption is critical in order to justify the assumption that yields are lower on new land.

While there is no doubt that the supply of good cropland may be limited, world land data show that land with good potential for crops is still available. Thus, "yield drags" from agricultural expansion, while plausible, are not necessarily a fact to be imposed without an examination of the evidence.

Some evidence of the extent of well-suited land still available can be obtained from the work of Fisher et al. (2002). Utilizing agro-ecological zones combined with land-cover information, these authors estimated that close to 19% of global land with rain-fed cultivation potential (very suitable, suitable, and moderately suitable in their classification) was under forest ecosystems at that time. This means that 464 million hectares of suitable cropland could be cultivated. Considering only very suitable land, about 237 million hectares could be cultivated. While expansion over forest ecosystems has large greenhouse gas consequences, the CARB analysis penalizes biodiesel twice: first by forest displacements, and second by yield reductions. The assumed yield reduction means that additional land must be converted to meet the growth in global demand for oilseeds.

Table 3 presents regional information extracted from Table 5.13 in Fisher et al. 2002. While the land used in crop cultivation refers to the 1994-1996 period, the table indicates that globally, only half of the land classified as moderately suitable for rain-fed cultivation potential or better was being used for that purpose.

The extent to which agricultural expansion for biofuel production must all be accommodated by a combination of forestland and pastureland conversion could also be questioned. A recent study (Campbell et al. 2008) concluded that between 385 and 472 million hectares of abandoned agricultural land (cropland and pasture) could be brought back into production. It is important to notice that this figure excludes abandoned agricultural land that had transitioned to other ecosystems such as forest. The authors highlight that their estimates are between 66% and 110% of the figures reported in previous assessments. This indicates the numbers are consistent with the range provided in other studies.

TABLE 3. Regional estimates of land-use availability

Region	Total land (10^6ha)	Land for Use in Crop Cultivation (FAOSTAT 1994-1996) (10^6ha)	VS+S+MS[a] Land with Rain-Fed Cultivation Potential (mixed inputs) (10^6ha)
North America	2,138.50	225.3	366.3
Eastern Europe	171	81.7	121.9
Northern Europe	172.5	21.6	43.8
Southern Europe	131.6	45.6	46.5
Western Europe	109.5	35.1	64.2
Russian Federation	1,674.10	130.1	225.9
Central America & Caribbean	271.8	43.5	58.8
South America	1,777.60	114.8	669.2
Oceania & Polynesia	849.7	53.2	101.8
Eastern Africa	639.5	46	240.9
Middle Africa	657.1	24.8	270.3
Northern Africa	794.1	44.1	94
Southern Africa	266.4	17.4	28.8
Western Africa	633	65.4	178.6
Western Asia	433	46.1	31.7
Southeast Asia	444.5	89.6	102
South Asia	671.8	231.6	196
East Asia & Japan	1,149.50	144.1	144.8
Central Asia	414.4	45.2	15.5
Developing	**8,171.50**	**909.6**	**2,024.70**
Developed	**5,228.00**	**595.5**	**976.1**
World total	**13,399.50**	**1,505.20**	**3,000.80**

Source: Fisher et al. 2002.

[a] VS=very suitable, S=suitable, MS=moderately suitable.

At a minimum, the assumption that "all suitable land has been converted to agriculture" should be modified and a new category of abandoned or idle cropland should be added, as was concluded in the previous section. We now turn to the second part of the premise, which states that "yields on newly converted lands are almost always lower than corresponding yields on existing cropland." This assumed fact is used to justify the steep yield discounts on new areas assumed by GTAP for the CARB analysis.

CARB assumes that new cropland that comes from pasture and forestland is intrinsically less productive than cropland that is planted in the baseline. CARB uses a parameter called the "elasticity of crop yields with respect to area expansion," which is justified and defined as follows: "This parameter expresses the yields that will be realized from newly converted lands relative to yields on acreage previously devoted to that crop" (CARB 2010, pp. 2 and 3). It seems clear that this parameter is not an elasticity but rather a simple ratio of yields on newly converted land relative to yields on existing land. To avoid confusion, we will follow the naming convention.

In the United States, this assumption may seem reasonable if we make the assumption that all "well-suited" cropland is currently being planted. But, as pointed out in the previous section, U.S. cropland has been going down over time because of increases in productivity and competing demands. If some of the cropland that has left agriculture is actually idled, then there exists a pool of available cropland that was once considered to be "well suited" for growing crops and could be consider "well suited" once again.

One pool of land that is available for planting is CRP. Secchi et al. (2009) estimated that the average productivity of Iowa land planted to corn and soybeans in 2006 was 71, as measured by the Corn Suitability Rating (CSR). The average productivity of Iowa land enrolled in the CRP in 2002 was 53. Using Secchi et al.'s yield equation that translates CSR into corn bushels, this means that yields on average CRP land are 21% lower than average yields on land that was planted in Iowa. However, this is a relevant statistic only if all CRP land is planted. The Secchi et al. data show that there were 300,000 acres of Iowa CRP in 2002 with a CSR that exceeded 71. The average CSR of the most productive 813,000 acres enrolled in CRP was 71. This means that Iowa cropland could expand by up to 813,000 acres (3.6% of Iowa corn and soybean acres in Iowa in 2006) without affecting the average yields. The actual increase in 2009 corn and soybean acres from 2006 corn and soybean acres was 500,000 acres, of which approximately 368,000 acres came from CRP. This means that the land brought into production in Iowa since 2006 could have been more productive than existing land.

The above discussion shows how difficult it is to determine the validity of the assumption that land brought into crop production is inherently less productive than land that was already in production even in the United States. However, U.S. crop ground that was idled was idled for a reason. It seems quite likely it was less productive than cropland that continued in production. The marginal cropland that came out of production was likely devoted to crops that had the lowest returns. Figure 8 shows the percentage change in acreage by crop from 2009 relative to 1998. This suggests that the returns to most crops declined substantially over this time relative to the returns to the crops that did not decline substantially, most notably corn and soybeans, with wheat and rice close behind. What this suggests is that most marginal crop acres probably came out of marginal crops.

One might be tempted to test the CARB assumption by determining if the crops that have lost the most acreage since 1998 have had the highest rate of yield growth because the remaining crop acreage is the most suited for growing the crop. But this would result in the perverse finding that the crops that have gained the most acreage (corn and soybeans) have also had the highest rate of yield growth, because it is well known that yield growth for corn and soybeans (especially corn) has outstripped yield growth of nearly every other U.S. crop. One reason why corn and soybean acreage has grown over

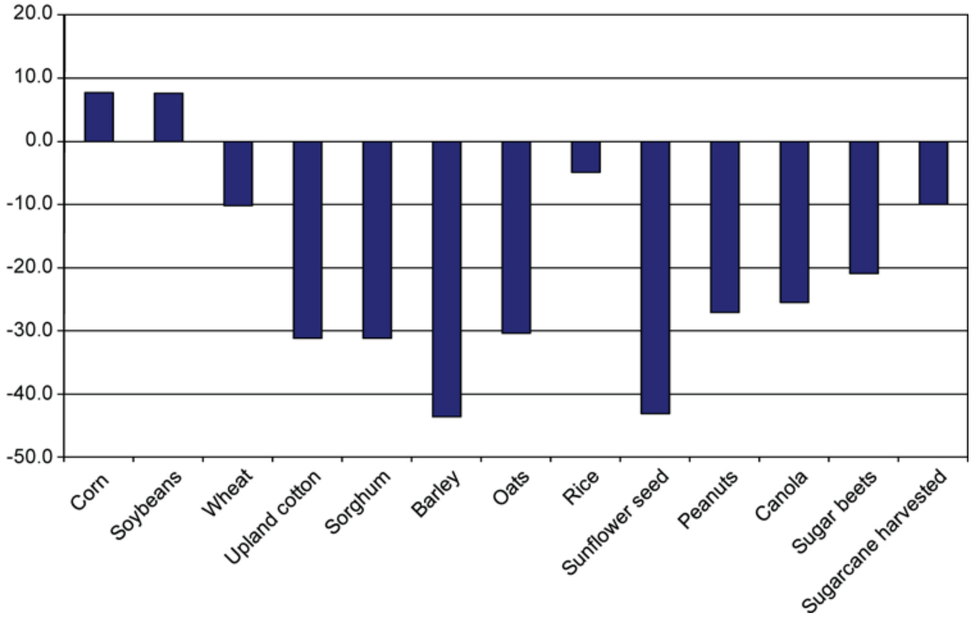


FIGURE 8. Percentage change in acres: 2009 versus 1998

time is precisely because of this differential yield growth. Higher yields make it more likely that farmers will choose to plant a crop.

This shift in crops makes it difficult to carefully test for or implement the CARB assumption in the United States. For example, with the biodiesel demand shock, CARB estimates that oilseed acreage increases and coarse grain acreage decreases, which makes sense if soybean acreage increases relative to corn acreage in response to an increase in the price of soybean oil. If new land is converted from hay or pasture, in response to the overall increase in crop returns, then which crop is likely to be planted on the new land? Because the reduction in cropland is associated with a reduction in marginal crops, it is reasonable to expect that marginal crops will be planted on the marginal lands. Any change in corn and soybean acreage will likely take place on land that is already being planted because that land is relatively more productive. For example, an expansion in soybean acreage will likely be met primarily by a reduction in corn acreage because most soybeans are grown in rotation with corn. If more soybeans are grown in the Corn Belt, it is difficult to see why soybean yields will drop. Rather, cotton yields or small grain yields that are planted on the new acreage could be lower if they are planted on marginal ground.

How crop mix changes in the United States is the key to understanding how crop yields will change in response to new land being cultivated. A test of the CARB assumption would require a careful accounting for the dramatic changes in crop mix that the United States has experienced in the last 10 years. Such a test is beyond the scope of this analysis.

However, the situation in Brazil allows for such a test because much of the expansion in cropland in Brazil is due to the dramatic increase in soybean acreage, so there is no doubt that soybeans have been planted increasingly on land that has been newly brought into production. If the CARB assumption is correct, then we should be able to see it in the Brazilian soybean yield data. In particular we should be able to discern if those regions in Brazil with the most rapid expansion have either lower yields or lower yield growth because of that expansion.

Testing Whether Yields on New Land Are Lower than on Old Land

Our test of whether yields on new land are lower than on old land needs to account for both the addition of new area and changes in yields over time.

Let *t* denote the base year, which defines what is existing on old land. The average reported yield at any point *n* years after the base year is given by

$$\overline{Y}_{t+n} = \frac{A^{old} Y^{old}_{t+n} + A^{new}_{t+n} Y^{new}_{t+n}}{A^{old} + A^{new}_{t+n}} \tag{1}$$

where A is land and $A^{new}_{t} = 0$. Suppose that yield on new land equals $Y^{new}_{t+n} = \gamma Y^{old}_{t+n}$, where γ is the crop yield parameter that measures the ratio of yields on new relative to old land. Equation (1) can then be rewritten as

$$\overline{Y}_{t+n} = \left(\frac{A^{old} + \gamma A^{new}_{t+n}}{A^{old} + A^{new}_{t+n}} \right) Y^{old}_{t+n} ,$$

with the reported yield being a scaled version of the yield that would have been observed in the base area. Because $A^{new}_{t} = 0$, the change of yields between the base and time *t+n* can be expressed as

$$\overline{Y}_{t+n} - \overline{Y}_{t} = \left(\frac{A^{old} + \gamma A^{new}_{t+n}}{A^{old} + A^{new}_{t+n}} \right) Y^{old}_{t+n} - Y^{old}_{t}$$

which can be rearranged as

$$\overline{Y}_{t+n} - \overline{Y}_{t} = \frac{A^{old}}{A^{old} + A^{new}_{t+n}} \left(Y^{old}_{t+n} - Y^{old}_{t} \right) + \frac{A^{new}_{t+n}}{A^{old} + A^{new}_{t+n}} \left(\gamma Y^{old}_{t+n} - Y^{old}_{t} \right), \tag{2}$$

which is a weighted average of the yield growth in the base area and an adjusted yield growth affected by γ. Thus, if the yield in new areas is lower than in base areas ($\gamma < 1$), equation (2) decreases with the share of new land on total land.

Defining $\alpha_n = \frac{A^{old}}{A^{old} + A^{new}_{t+n}}$, equation (2) can be rewritten as

$$\overline{Y}_{t+n} - \overline{Y}_{t} = \alpha_n \left(Y^{old}_{t+n} - Y^{old}_{t} \right) + \left(1 - \alpha_n \right) \left(\gamma Y^{old}_{t+n} - Y^{old}_{t} \right). \tag{3}$$

If we assume yields on established areas grow at constant trend of $\delta = Y^{old}_{t+1} - Y^{old}_{t}$ for all *t*, equation (3) becomes

$$\overline{Y}_{t+n} - \overline{Y}_t = \alpha_n n\delta + (1-\alpha_n)\left(\gamma\left(Y_t^{old} + n\delta\right) - Y_t^{old}\right)$$

or

$$\overline{Y}_{t+n} - \overline{Y}_t = \alpha_n n\delta + (1-\alpha_n)\gamma Y_t^{old} + (1-\alpha_n)n\gamma\delta - (1-\alpha_n)Y_t^{old}. \tag{4}$$

Notice that equation (4) is increasing in γ, with

$$\frac{\partial\left(\overline{Y}_{t+n} - \overline{Y}_t\right)}{\partial\gamma} = (1-\alpha_n)\left(Y_t^{old} + n\delta\right) > 0. \tag{5}$$

A direct regression of equation (4) (for δ and γ) has its problems since α_n is perfectly correlated with $(1-\alpha_n)$. Notice however that, in the absence of yield drags ($\gamma = 1$), rearranging equation (4) we obtain

$$\frac{\overline{Y}_{t+n} - \overline{Y}_t}{n} = \delta,$$

where the left-hand side is observable and the right-hand side is an unknown constant. This suggests a way to test whether land expansion effects yield growth. In terms of a model, one could run

$$\frac{\overline{Y}_{t+n} - \overline{Y}_t}{n} = \beta_o + \beta_1 X_n, \tag{6}$$

where X_n is a variable that affects average yield growth if yields on new and established lands are different. Examples of possible regressors are A_{t+n}^{new} or $\frac{A_{t+n}^{new}}{A^{old} + A_{t+n}^{new}}$. The share of new land may be preferred because of large differences in land across regions.

The null hypothesis that yields on new and old areas are the same (i.e., $\gamma = 1$) is to test whether $\beta_1 = 0$, versus the alternative $\beta_1 \neq 0$. However, if the null hypothesis is rejected, we would want to know if this is because a yield drag is present (i.e., if $\gamma < 1$). Given equation (5), if $\gamma < 1$ then

$$\frac{\overline{Y}_{t+n} - \overline{Y}_t}{n} < \delta.$$

In terms of the model (6), and for $X_n > 0$, the null hypothesis that yields on new lands are lower than yields on established areas is $\beta_1 < 0$. In this way, we have a one-sided test. Before moving to a statistical test, a visual examination of yield and yield growth data reveals that the CARB assumption in Brazil does not immediately show up in the data.

Data

Table 4 shows how three-year average regional soybean yields vary with expansion of soybean area in Brazil. Figure 9 plots the same yields in the last three-year period against total soybean area expansion in Brazil. Figure 10 plots the same yields by region against total cropland expansion. If new land were less productive than old land, then we would expect to see a negative relationship. Figures 9 and 10 do not support this assumption. If anything, the data support a positive relationship. Thus, there is no obvious support for the hypothesis that the yield of newly converted land is less than the yield of new soybean land in Brazil.

However, this finding can also be explained by differences in intrinsic land quality, in that regions that have had the most land expansion could be the regions with the best growing conditions. If true, then the assumption of CARB is still contradicted, but it

TABLE 4. Regional soybean yields and area in Brazil

	South	Southeast	West Central	Amazon	Northeast
			Area (million ha)		
1996-98	5.68	1.07	3.70	0.64	0.64
1999-01	6.03	1.13	4.57	0.88	0.92
2002-04	7.52	1.56	6.73	1.54	1.39
2005-07	8.48	1.70	8.03	2.22	1.82
2008-10	8.38	1.46	7.59	2.50	1.94
			Yield (tons/ha)		
1996-98	2.17	2.17	2.49	2.65	1.98
1999-01	2.29	2.42	2.80	2.96	2.24
2002-04	2.38	2.61	2.76	2.96	2.26
2005-07	2.16	2.61	2.62	3.16	2.57
2008-10	2.44	2.83	2.94	3.08	2.82

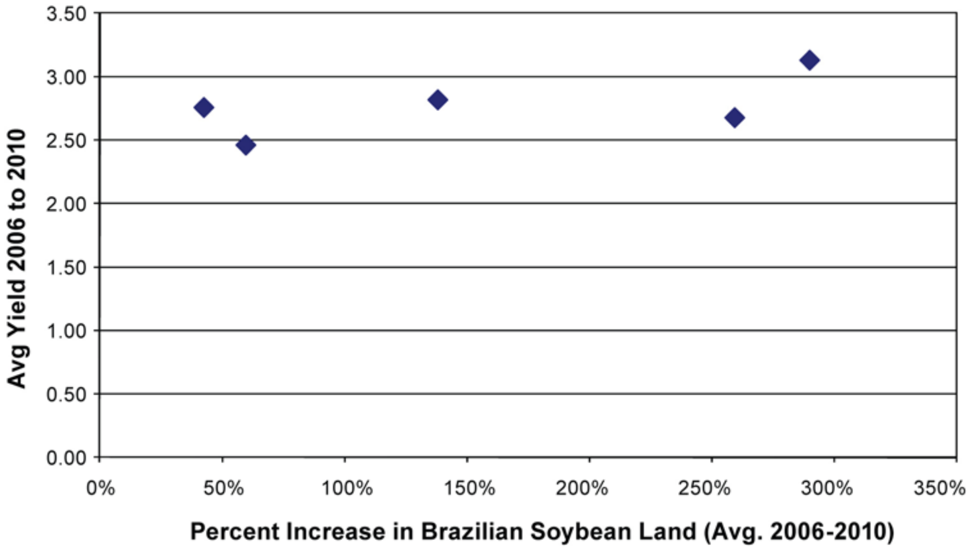


FIGURE 9. Relationship between recent soybean yields and soybean land growth

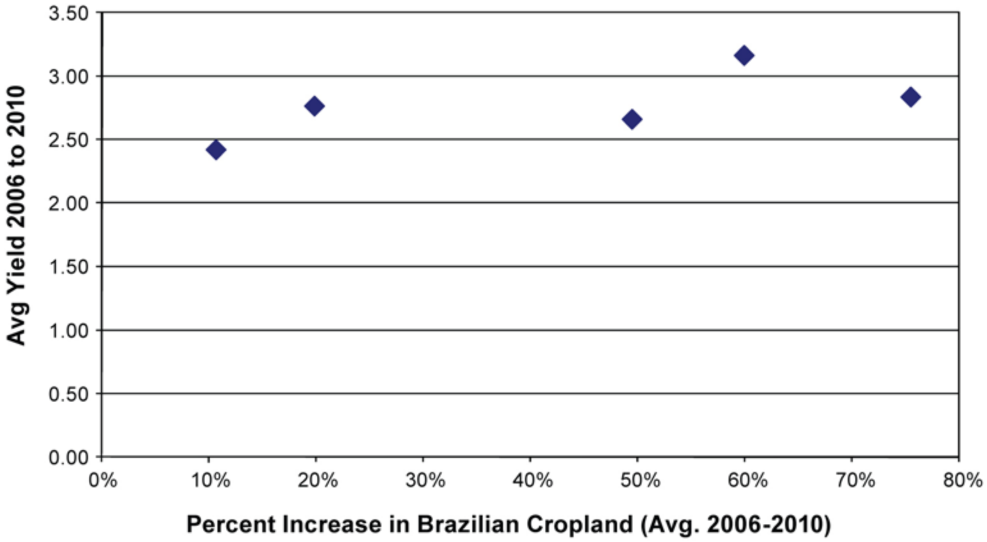


FIGURE 10. Relationship between recent soybean yields and cropland growth

could still be true that yield growth could be negatively impacted by land expansion. Such a finding would imply that regional average yields in Brazil would be even higher had land expansion not occurred. Equation (6) is used to test this hypothesis.

A strict application of equation (6) would use actual yields in the base year and subsequent years to calculate the dependent variable $\frac{\overline{Y}_{t+n} - \overline{Y}_t}{n}$. If the base-period yield

$\overline{Y}_t$, is equal to trend yield in year t with no land expansion, then the expected value of the dependent variable equals trend yield. However, if weather conditions are such that the base-period yield is higher or lower than trend yield, then the expected value of the dependent variable is either lower or higher than trend yield. Thus, the implementation of equation (6) requires some care in selection of a base-period yield.

Two alternative definitions are used. The first alternative uses the predicted value of 1996 yields from a regression of actual yields on time by region. This alternative greatly reduces the impact of weather conditions on the base-period yield, but it also introduces the possibility that the predicted yield in the base period could be affected by the impacts of land expansion in subsequent periods. The second alternative is to use a three-year average of yields from 1996 to 1998 as the base-period yield. This lessens any impact of land expansion in subsequent years but is more susceptible to abnormal growing conditions in the first three years.

It is important to account for regional differences, so regional intercept terms are allowed. Two alternative measures of land expansion are used. The first is the share of new cropland by region. The second is the share of new soybean land by region.

Table 5 shows the regression results. All the intercept terms (the coefficients corresponding to the region variables) are positive, as expected. All four models result in a negative coefficient on the share of new land, which is suggestive that if cropland expansion had been less, then yield increases would have been greater. However, none of estimated coefficients is statistically different from zero. (T-statistics are given in parentheses.) Therefore the null hypothesis that expansion of cropland has had no impact on yield growth cannot be rejected.

Not rejecting the null hypothesis simply means that the evidence is not strong enough to conclude that land expansion has affected yield growth. However, if it has affected yield growth, then one would expect that soybean yield growth would be lowest in the regions with the most expansion. Figures 11 and 12 show that this simply is not the case. The figures show that trend yields do vary across regions, but if anything, those regions with a higher growth in land have a higher growth in yields.

TABLE 5. Regression results

	Soybean Land		Total Land	
Variable	**1996 Trend Yield**	**3-Yr. Average**	**1996 Trend Yield**	**3-Yr. Average**
Region1	0.018	0.016	0.017	0.014
Region2	0.047	0.050	0.046	0.050
Region3	0.029	0.041	0.030	0.044
Region4	0.044	0.056	0.038	0.051
Region6	0.074	0.063	0.069	0.059
Share of New Land	-0.006	-0.007	-0.021	-0.033
t-statistic	(-1.15)	(-1.44)	(-0.71)	(-1.16)

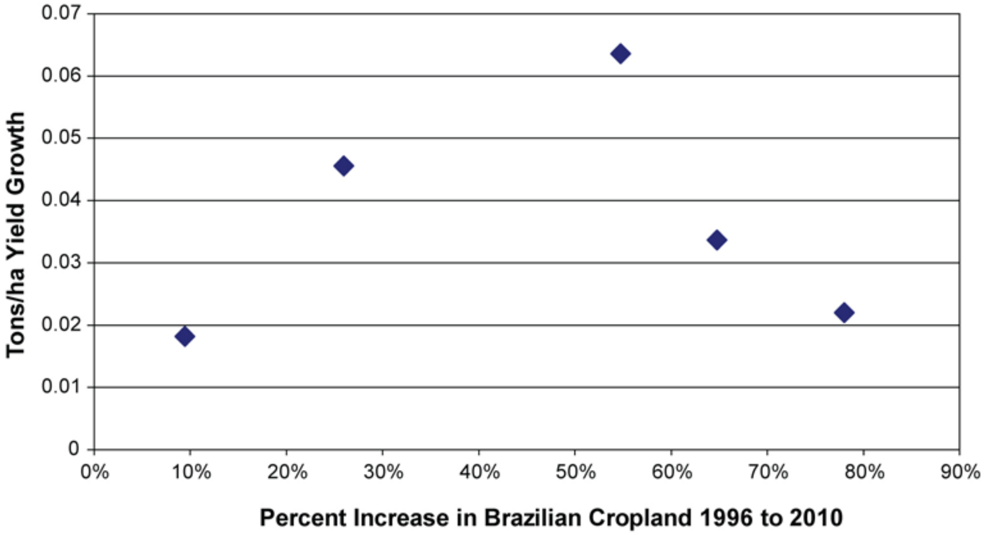


FIGURE 11. Relationship between soybean yield growth and cropland growth

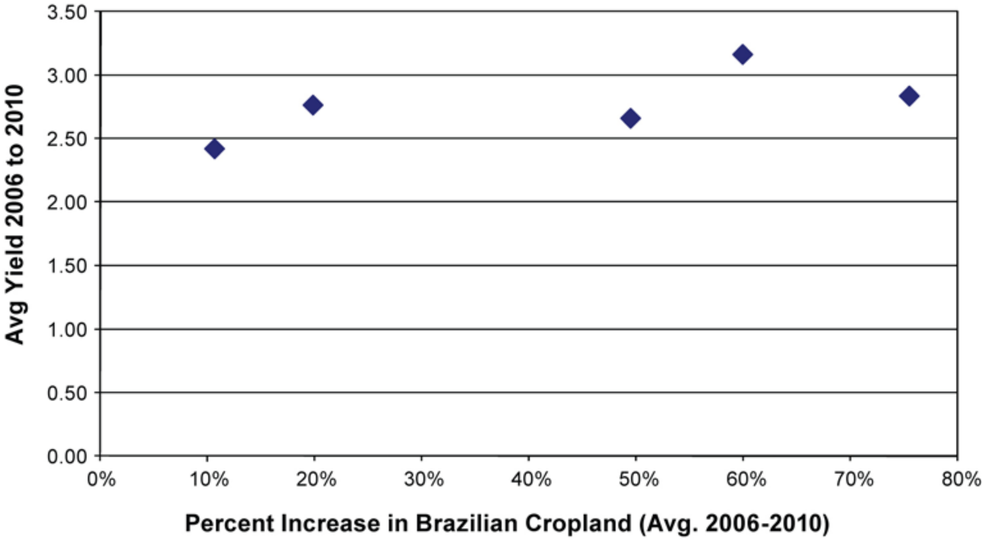


FIGURE 12. Relationship between soybean yield growth and soybean land growth

Summary

The CARB assumption that yields on new land are lower than yields on currently planted land seems straightforward. After all, if the new land were more productive than existing land, then farmers would be planting the new land rather than the old land. But a closer look at the situation in the United States and Brazil shows that the actual situation is more complicated than this common-sense view of farmer decision making.

In the United States, the last 15 years have seen dramatic changes in the mix of crops grown and a significant drop in the aggregate amount of cropland being planted. This change in crop mix was facilitated by the 1996 farm policy changes that dramatically reduced the incentive to grow particular crops for farm subsidies. Large reductions in acres devoted to crops other than corn, soybeans, wheat, and rice have resulted. This change in crop mix combined with a reduction in aggregate acreage means that, on average, marginal land that went out of production had been devoted to producing the least profitable crops. One key factor that determines profitability is crop yield. Those crops with lower yields and lower yield growth are less profitable, holding all else constant. This suggests that a biofuels demand shock that leads to an expansion in the demand for either corn or soybeans will result in most additional corn or soybeans being planted on existing cropland rather than on new cropland, if the new cropland is actually the cropland that went out of production. Because it was the acreage of marginal crops that was planted, on average, on land that went out of production, it would also be the marginal crops that are planted on any new land that comes into production. Existing land would be allocated, on average, to the more productive crops if the existing land is more productive than the new land. Because the shifting of crops between production regions in the United States is far more important in determining the impacts of crop area expansion on yields than the intrinsic productivity of land, it seems prudent to infer yield changes from a change in demand for a crop by measuring where the crop is likely to be grown at the margin. Given the U.S. experience, this means that the marginal yield on land devoted to crops likely varies dramatically across crops.

In the GTAP model, the broad crop categories (oilseeds, coarse grains, other grains, and other crops) makes it difficult to differentiate between marginal crops and non-marginal crops because each category contains both. Thus, it seems that it would be difficult for the GTAP framework to reasonably allocate new land to marginal crops in a way that is consistent with the U.S. experience. It seems reasonable to conclude that marginal U.S. land that is brought into production in response to an increase in the demand for corn and soybeans is less productive than existing land. However, the share of marginal land that is actually devoted to the production of corn and soybeans rather than marginal crops is likely low. Corn and soybeans will be largely planted on existing land, with marginal crops being planted on marginal land.

The situation in Brazil is far different, however, because the recent large expansion in crop acreage allows for a direct test of the assumption that new land is less productive than old land. Because the dominant crop in Brazil is soybeans, it is appropriate to measure whether this assumption holds for soybean yields. Using soybean yields as a metric, there is no support for the hypothesis that the Brazilian land that has been brought into production since 1996 is less productive than land that was already planted in 1996. If anything, the aggregate data suggest that yields and yield growth are highest in the regions that have expanded the most. At a minimum, this suggests that for Brazil, the "elasticity of crop yields with respect to area expansion" should have a central value of 1.0. This rejection of the assumption that new land is less productive than existing land is consistent with a frontier country where transportation costs limit production rather than the intrinsic productivity of land.

Capturing Production from Double Cropping in GTAP

Before expanding into new area in response to a price increase, it is expected that producers explore increasing the productivity of their existing land. The analysis conducted for CARB acknowledges and partially captures this observation by making yields responsive to changes in returns. However, the analysis seems to ignore another form of intensification available to producers in many areas of the world, namely, using the same land to generate more than one crop per year. One of the first farmer responses to higher crop prices is an increase in the amount of double cropping that takes place. Double cropping in the United States generally consists of planting soybeans after winter wheat is harvested. Figure 13 shows that the number of acres of double-cropped soybeans increased substantially in 2007 and 2008 in response to higher crop prices.

In Brazil, double cropping consists of planting a crop of corn after a crop of soybeans. This second crop of corn is referred to as "safrinha." Figure 14 shows that total Brazilian safrinha has increased substantially over the last 15 years.

If all safrinha corn is on land used for the main summer crop (usually soybeans), output expands without the need for new land to be brought into production. It is "as if" yields per unit of land cropped are increasing faster than usually assumed by "technology" and price responsiveness. To illustrate the potential of double cropping to accelerate yield growth per unit of land, Figure 15 shows the evolution of corn yields for the first crop, and the implied combined corn yield. This implied combined yield is calculated as total corn production divided by the area of the first crop of corn. The implicit assumption is that all the area planted to the second crop of corn had been planted in the main season. For the last year in the figure, double cropping implies yield increases of over 50% when compared to those based on the first crop alone.

It is important to account for double-cropped acres because double cropping creates production without using up land. Hence, an increase in double cropping can help accommodate expanded biofuels production without causing conversion of pasture or forest to cropland. The challenge of properly accounting for double cropping is that no land category called double-cropped land exists in GTAP. However, because an increase in double cropping increases production without increasing land, it is as if yield increases. And GTAP captures increases in yield through the yield elasticity with respect to price. So this yield elasticity could be adjusted to account for increased production from double cropping.

Adjusting Price-Yield Elasticities

When there are double crop acres, it is typical for reporting agencies to calculate yield by dividing total production of the crop by total acres planted to the crop. That is

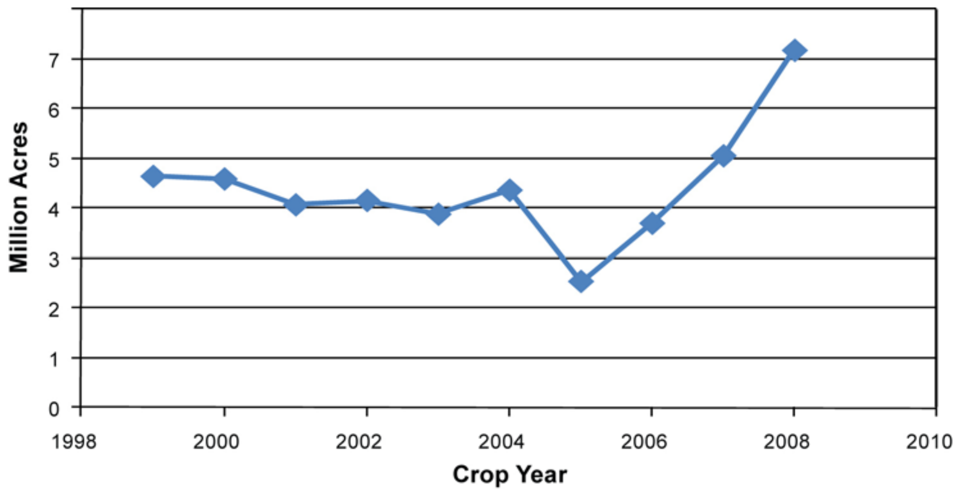


FIGURE 13. Number of double-cropped soybean acres in the United States

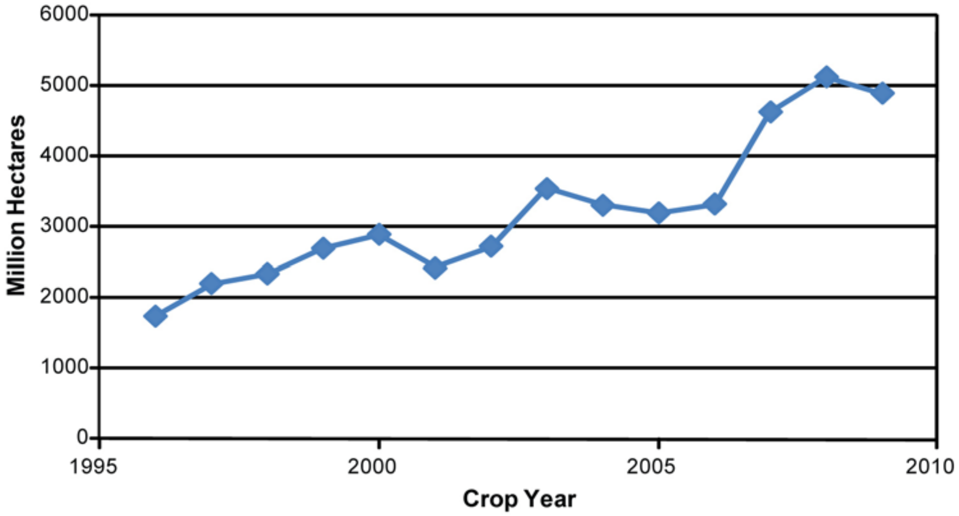


FIGURE 14. Safrinha (double-cropped corn) land in Brazil

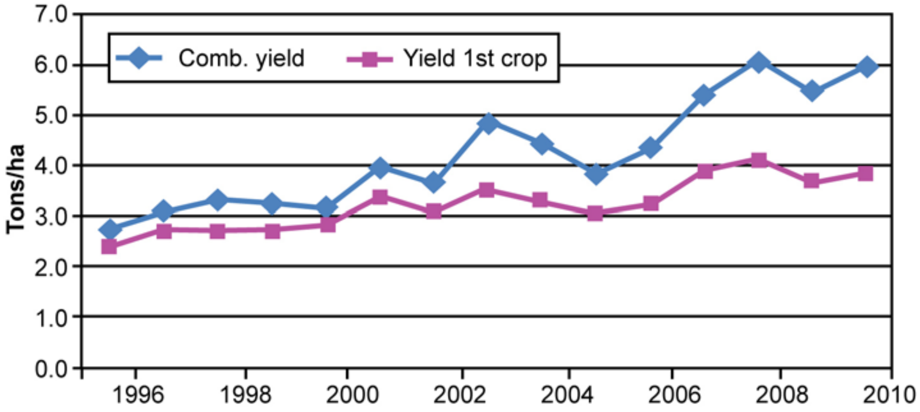


FIGURE 15. Corn yields for the first crop and the implied combined yield

$$Y = \frac{Q}{A_1 + A_2}; \quad Q = A_1 Y_1 + A_2 Y_2 \tag{7}$$

where Y is the reported yield of a crop (soybeans), A is land devoted to soybeans, and the subscript denotes first crop or second crop. The yield elasticity with respect to price is meant to capture how yield changes in response to price. However, yield is not measured directly. Rather aggregate production and total acreage are measured and yield is calculated by division. This means that price affects reported yields through both its impact on acreage and on per acre yields:

$$\frac{\partial Y}{\partial P} = \frac{A_1(\frac{\partial Y_1}{\partial P}A_1 + \frac{\partial A_1}{\partial P}Y_1 + \frac{\partial Y_2}{\partial P}A_2 + \frac{\partial A_2}{\partial P}Y_2) - \frac{\partial A_1}{\partial P}(Y_1A_1 + Y_2A_2)}{(A_1 + A_2)^2}$$

which implies

$$\frac{\partial Y}{\partial P}\frac{P}{Y} = \frac{A_1(\frac{\partial Y_1}{\partial P}\frac{P}{Y}A_1 + \frac{\partial A_1}{\partial P}\frac{P}{Y}Y_1 + \frac{\partial Y_2}{\partial P}\frac{P}{Y}A_2 + \frac{\partial A_2}{\partial P}\frac{P}{Y}Y_2) - \frac{\partial A_1}{\partial P}\frac{P}{Y}(Y_1A_1 + Y_2A_2)}{(A_1 + A_2)^2}.$$

This expression can be greatly simplified by expressing it in terms of elasticities. Denoting the elasticity of *i* with respect to a change in *j*, as $\eta_{i,j}$, after simplifying, the price yield elasticity equals

$$\eta_{y,P} = s_1\left[\eta_{y_1,P} + \eta_{A_1,P}\right] + s_2\left[\eta_{y_2,P} + \eta_{A_2,P}\right] - \frac{A_1}{A_1 + A_2}\eta_{A_1,P} - \frac{A_2}{A_1 + A_2}\eta_{A_2,P} \tag{8}$$

where the share of production is denoted by s.[7] Equation (8) makes it clear that the yield elasticity with respect to price measures changes in per acre yields on both first and second crop acreage, as well as changes in both first- and second-crop acreage.

If we want to measure the elasticity holding acreage constant then

$$\eta_{y,P} = s_1\eta_{y_1,P} + s_2\eta_{y_2,P}$$

which is just the share-weighted elasticities of yield on first- and second-crop acreage.

From a land-use perspective, increased production on second-crop acreage implies that less land is needed to meet any given demand. This is exactly analogous to what happens when yield increases: demands can be met with fewer acres of land. From

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[7] This derivation was accomplished by noting that Y = Q/A, and then multiplying and dividing by the appropriate variable to turn the derivatives into the resulting elasticities.

equation (7), we can capture the additional production from second-crop acreage in response to a price increase by accounting for production changes in the numerator but holding second-crop acreage constant in the denominator. When acreage is allowed to change this gives rise to a new yield elasticity with respect to price:

$$\eta^*_{y,P} = s_1\left[\eta_{y_1,P} + \eta_{A_1,P}\right] + s_2\left[\eta_{y_2,P} + \eta_{A_2,P}\right] - \frac{A_1}{A_1 + A_2}\eta_{A_1,P}. \tag{9}$$

All that changes is that the elasticity of second-crop acreage with respect to price no longer appears in the expression. That is, if we subtract the unadjusted elasticity from the adjusted elasticity the difference is $\frac{A_2}{A_1 + A_2}\eta_{A_2,P}$. This means that we can account for the impacts of increased production on second-crop acreage by simply adding this term to the GTAP elasticity that is currently being used.

Alternatively, if the GTAP yield elasticity is supposed to hold acreage constant, then we want to account for increased production caused by an increase in double-cropped acreage. Then

$$\eta^*_{y,P} = s_1\eta_{y_1,P} + s_2\eta_{y_2,P} + s_2\eta_{A_2,P} \tag{10}$$

and the only difference between the current GTAP elasticity and the adjusted elasticity that accounts for the additional production from double-cropped acreage is $s_2\eta_{A_2,P}$. Notice that the only difference in the two adjustment factors is that when acreage is allowed to change, then the adjustment factor includes the double crop share of acreage. When changes in acreage are not accounted for then the adjustment factor includes the share of production. Because yields on second-crop acreage are typically lower than yields on first-crop acreage, the adjustment will be lower when acreage changes are not accounted for.

Application to U.S. Soybeans

The share of acreage and production of double-cropped soybeans in the United States can vary dramatically. USDA reports yields of soybeans following another crop and not following another crop for Arkansas and Missouri only. The average yield difference for these two states was 17.5%. Figure 16 uses this yield difference and the estimate of total double-cropped acres from the Food and Agricultural Policy Research Institute (FAPRI) to calculate shares from 2000 to 2008.

The remaining step is to calculate the elasticity of double-cropped acres with respect to price. Figure 17 shows both soybean returns per acre and the number of acres of double crop. Although the relationship is not consistent over time, the sharp increase in soybean returns beginning in 2007 is associated with a large increase in double-cropped acres. Because there is a limit to the number of farmers and the regions where double cropping is feasible, it is likely that the elasticity of double-cropped acres is high when

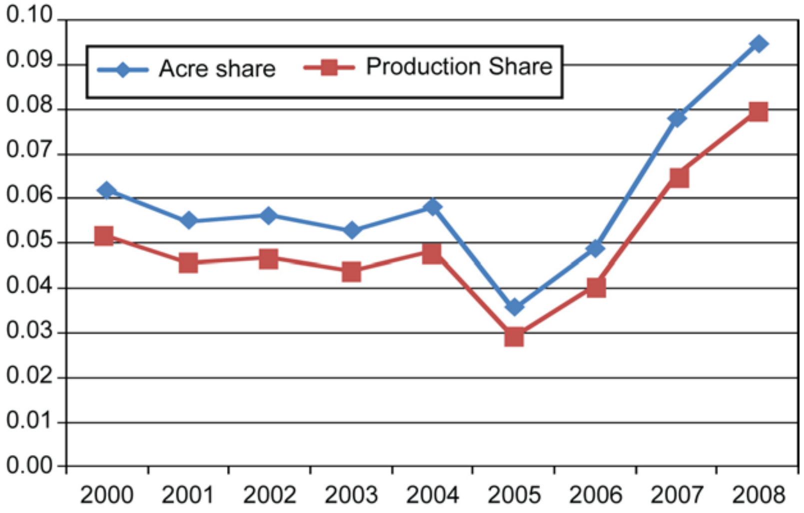

FIGURE 16. Share of double-cropped acres

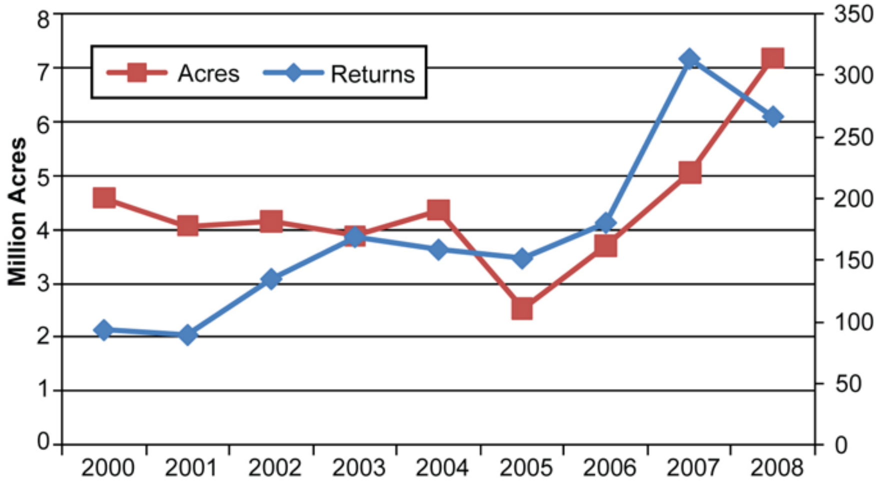

FIGURE 17. Comparing U.S. double-cropped acres and soybean returns

acreage is low and low when acreage is high. Hence, it is not clear what value to use. An upper limit would be to calculate the percentage change in returns averaged in 2005 and 2006 relative to 2007 and 2008 and to calculate the corresponding average double-cropped acres. This results in a return elasticity of 1.3. This translates into a price elasticity (holding costs constant) of approximately 2.0. This elasticity is an upper bound and is appropriate when double-cropped acreage is quite low, as it was in 2005 and 2006. If we multiply the share of acreage in 2005 and 2006 by 2.0, we get an adjustment to the soybean yield elasticity of between 0.07 for 0.085. Thus if the central yield elasticity used by CARB is 0.3, we would increase this central point to 0.37 or 0.385 for soybeans. Note that an increase in share from 2007 to 2008 shown in Figure 17 is likely associated with a decrease in the elasticity; the actual amount of adjustment is not likely to differ by much across years.

Adjustment for Brazil

In Brazil, corn is double cropped after soybeans. The yield elasticity of corn could be increased to accommodate the production increase from double cropping, using the same procedure as was used for the United States. Or, focus could remain on soybeans, and the double-cropped acreage could be accounted for by allowing total corn acreage to increase by the amount of the double-cropped acreage and counting the production of soybeans on the double-cropped acreage as accruing to soybeans but subtracting the acreage that is double cropped from reported soybean acreage. The total number of acres in production is the same for either treatment. Given that the focus of the CARB biodiesel analysis is on soybeans, it makes sense to account for the extra production from double cropping as accruing to planted soybean land that is not double cropped.

Second-crop corn yields about 7% less than first-crop corn in Brazil. Thus, there is a much smaller difference between the share of production and the share of acreage. The share of acreage that is double cropped in Brazil from 2000 to 2009 is shown in Figure 18. A share of 20% seems reasonable to use to calculate the adjustment factor. There was a 150% increase in double cropping from 2004 to 2006 relative to 2007 to 2009. This was associated with an increase in the profitability of growing the second crop of corn.

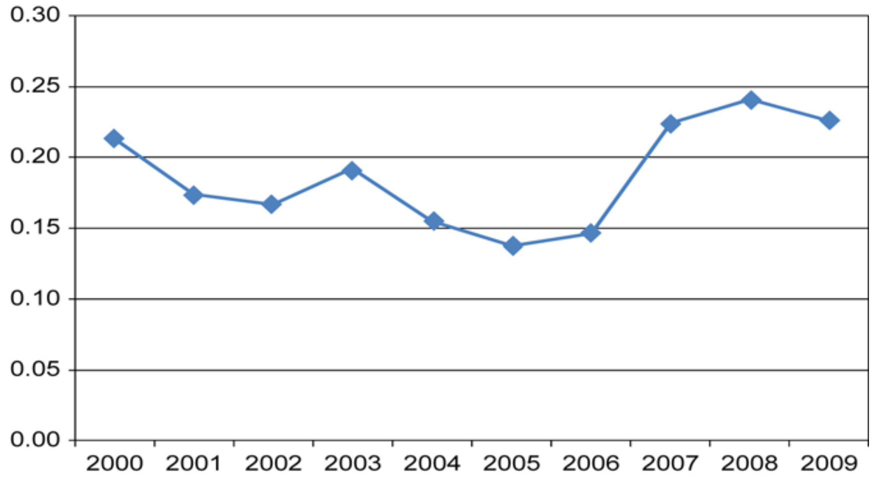

FIGURE 18. Share of Brazilian soybeans grown in double cropping system

Taking the average percentage changes over this time period gives a return elasticity equal to 1.13. This translates into a price elasticity (holding costs constant) of approximately 1.6. Again, this is likely an upper limit on the elasticity. But if we multiply 1.6 by 0.15, which is the approximate share in 2004, we get an adjustment factor for Brazil equal to 0.24. Therefore, if the GTAP yield elasticity is 0.25, the adjustment factor would increase the elasticity to 0.49. Note that this adjustment is much larger than the U.S. adjustment. This reflects the larger share of double cropping in Brazil.

One difficulty with implementing this adjustment would be if GTAP does not allow the elasticity of yield with respect to price to differ by crop. Both in the United States and Brazil, the soybean crop is involved with double-cropping systems. If the increase in production from double cropping is attributed in both cases to soybeans, then the elasticities for the other crops should not be adjusted.

Concluding Remarks

The use of economic models to guide agricultural and trade policy decisions is not new. Models developed by USDA, FAPRI, GTAP, Food and Agriculture Organization and Organization for Economic Cooperation and Development have been used repeatedly over the last 30 years to good purpose. These same models are now being asked to estimate the extent to which market-driven land-use changes from expansion of biofuels offset the direct emission reduction from substitution of biofuels for petroleum fuels. Thus, the models are now being used in a regulatory role rather than an advisory role. In an advisory role, model predictions could be treated as indicators of the direction and magnitude of changes that would come about from a change in policy. In a regulatory role, model predictions can mean the difference between expansion of biofuels production or the complete shutdown. When elected legislators make policy decisions that were perhaps guided by model results, then they are held accountable at the ballot box for their decisions. When regulators run models, then the models can be held responsible for the outcomes. It seems reasonable to expect a much higher threshold of reliability and accuracy for models that are used in a regulatory role rather than an advisory role.

Economists know that expanded agricultural production will require some additional land. This means that expansion of U.S. biofuels will result in more land being devoted to crop production on an aggregate worldwide basis. However, given all the forces that affect agricultural production decisions, it is difficult, if not impossible, to attribute any given agricultural development project to U.S. biofuels expansion, which is why CARB and the Environmental Protection Agency have to rely on models that attempt to isolate the effects of U.S. biofuels.

The financial stakes involved in the estimation of land-use changes from biofuels have created a large incentive for interest groups to know more about the models and the approaches that are used. Those whose interests have been harmed by model estimates will have an incentive to identify and change model assumptions and approaches that will serve their interests. Given the lack of data and detailed knowledge about exactly how the world's producers and consumers will respond to a change in U.S. policy, the models used to estimate land-use changes are populated with parameters that reflect judgment calls, modeler insights, and economic wisdom rather than hard data. Thus, these models, like most economics models, are ripe ground for improvements that are informed by better data, improved insight, and greater transparency. This purpose of this staff report was to offer some of each.

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