CARB LCFS Expert Working Group - Sub-task #3

Investigation about:

g) Reconciliation of agricultural land (land transformation elasticity).

h) Elasticity with respect to area expansion for different land cover types.

Literature Review

One important GTAP model parameter used in the California LCFS calculation by CARB is the "elasticity of crop yields with respect to area expansion". It expresses the yields that will be realized from newly converted lands relative to yields on acreage previously devoted to that crop. In page IV-20 of the Staff Report, it is asserted that: "…because almost 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 crop lands."
It can be true in the United States and the European Union, however, in many other parts of the world, as in Latin America, there is considerable potential well-suited agricultural area for crop expansion. Some studies have shown this potential in terms of land available to agriculture or biomass production, as Chou et al. (1977), Edmonds and Reilly (1985) and Bot et al. (2000). Such research suggests that the elasticity of crop yields with respect to area expansion is *potentially larger* in those regions with *larger land availability*.

More importantly, the GTAP model is highly sensitive to the value of this elasticity since the indirect land use change carbon intensity can vary more than 75% when this elasticity is changed from 0.25 to 0.75. We note that CARB staff chose values ranging from 0.5 to 0.75 (except one scenario for sugarcane ethanol in which 0.8 was used for Brazil) to be used in the GTAP model runs though there is no explanation to the basis of such decision. In fact, from a microeconomic perspective, we would hardly expect investments in new areas if the yield of the new crop would be half of the traditional area, as assumed with an elasticity of 0.5 proposed by CARB staff.

We intend here to investigate the literature for possible estimates or evidences about the CARB assumption about this parameter. We notice that this was not something the literature has cared about, and the references about it are, in the majority, working papers or research reports not yet published in peer review journals.

Babcock and Carriquiry (2010) have investigated the validity of the assumption made by CARB about land converted to cropland being less productive than traditional cropland areas. They build an econometric model to test the hypothesis of decreasing yields in soybean production in Brazil related to expansion of soybean area and agricultural land. They conclude that the hypothesis that the yield of newly converted land is less than the yield of new soybean land in Brazil can not be confirmed, and so there is not enough evidence to conclude that land expansion has affected yield growth in that country.

Al-Riffai et al. (2010) have investigated the environmental impact of the EU biofuels mandate using IFPRI general equilibrium Mirage model, a model built in part based on GTAP. They followed the GTAP and CARB assumptions that marginal land productivity in all regions is half the existing average productivity, but did not present any rationality about such assumption. Curiously, they increase this ratio to 75% for Brazil.

Tyner et al. (2009) have estimated the land use changes and carbon emissions related to a US corn ethanol program using the GTAP model. They have improved the GTAP model to better represent byproducts from ethanol production and have assumed that the ratio of average and marginal productivities (the elasticity of crop yields with respect to area expansion) is equal to 0.66. This value is higher than the 0.5 value assumed by CARB. The same number is used by Hertel et al. (2010), who affirms that there is no strong evidence about such value, and such lack of evidence is a lacuna that needs do be investigated by the scientific community.

Tyner et al. (2010), keeping the investigation about impacts of a US corn ethanol program, have improved the GTAP model in several ways. The most important change has to do with the ratio of marginal and average productivities, what CARB has denominated as elasticity of crop yield with respect to area expansion. As they explain, it measures the productivity of new cropland versus the productivity of existing cropland. They come up with a set of regional values for this parameter, at the AEZ level, which is obtained from a bio-process-based biogeochemistry model, known as the Terrestrial Ecosystem Model (TEM) (Zhuang et al., 2003)[1]. TEM is well-documented and has been used to examine patterns of land carbon dynamics across the globe including how they are influenced by multiple factors such as CO_2 fertilization, climate change and variability, land-use change, and ozone pollution.[2] So, the elasticity of crop yield with respect to area expansion in the Tyner et al (2009) improved version of GTAP vary across the world and among AEZs. They found that this approach reduces the impacts on land use changes, since the land conversion factors in several AEZs are higher than the single conversion factor of 0.66 used in earlier work. The conversion factors from the TEM model are shown in table A2. In this table zero means no land is available and 1 shows that the marginal and average productivities are equal. Table A2 indicates that the US land conversion factors range from 0.51 to 1, depending on the AEZ. Table A2 shows that the Brazil land conversion factors range from 0.89 to 1, and most of them are around 0.9. This means that previous estimates were underestimating the marginal productivity of land in regions as Brazil.

[1] TEM is a process-based ecosystem model that uses spatially referenced information on climate, elevation, soils, vegetation and water availability to estimate monthly vegetation and soil carbon and nitrogen fluxes and pool sizes at the 0.5 by 0.5 degree of latitude and longitude.

[2] TEM has been also applied in combination with an economic model in some peer reviewed integrated analysis of biofuels inpacts on the global emissions. See for example Melillo et al. (2009).

Table A2. Regional land conversion factors obtained from NPP data for a generic C4 crop[1]

AEZ[2]\Region[3]	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	R19
1	0.00	0.00	0.91	0.00	0.00	0.00	0.93	1.00	0.95	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.68	0.61	1.00
2	0.00	0.00	0.92	0.00	0.00	0.00	0.89	1.00	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59	1.00	1.00
3	0.00	0.00	0.93	0.00	0.00	0.00	0.86	1.00	0.90	0.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00	0.89	0.74
4	0.00	1.00	0.89	0.00	0.00	1.00	0.93	1.00	0.88	0.00	0.88	0.89	1.00	0.00	0.00	0.00	0.86	0.92	0.92
5	0.00	0.00	0.93	0.00	0.00	0.90	0.98	0.88	0.90	0.00	0.90	0.91	0.98	0.00	0.00	0.00	0.00	1.00	0.96
6	0.00	0.00	0.91	0.00	0.00	0.88	0.98	0.97	0.85	0.00	0.88	0.95	0.78	0.00	0.00	0.00	0.00	1.00	0.88
7	0.73	0.00	0.00	0.89	0.00	0.80	0.90	0.59	1.00	1.00	0.00	0.00	0.43	1.00	0.98	0.00	0.46	0.80	0.65
8	0.71	0.90	0.00	0.91	0.00	1.00	0.71	0.72	0.90	1.00	0.00	0.00	0.60	0.84	0.84	0.00	0.71	0.79	0.86
9	1.00	1.00	0.00	0.85	1.00	0.98	0.88	1.00	0.91	1.00	0.00	0.00	1.00	0.94	0.82	0.00	0.77	0.84	0.93
10	0.93	0.96	0.88	0.88	0.96	0.84	1.00	0.89	1.00	0.93	0.00	1.00	0.92	0.89	0.89	0.87	0.98	0.88	0.92
11	0.96	0.83	1.00	1.00	0.94	0.95	0.90	1.00	0.87	0.84	0.00	1.00	0.79	0.89	1.00	0.00	0.00	0.77	0.96
12	0.89	0.86	0.91	0.00	0.95	0.92	0.90	1.00	0.84	0.00	0.00	1.00	1.00	0.00	0.89	0.00	0.00	1.00	0.98
13	0.92	1.00	0.00	0.55	0.00	1.00	1.00	0.00	1.00	1.00	0.00	0.00	1.00	0.63	0.97	0.00	0.00	0.00	0.00
14	0.51	0.89	0.00	0.80	0.00	0.92	1.00	0.00	1.00	1.00	0.00	0.00	1.00	0.90	1.00	0.95	0.00	0.00	0.00
15	0.71	0.90	0.00	0.83	1.00	1.00	1.00	0.00	0.64	1.00	0.00	1.00	1.00	0.90	1.00	0.87	0.00	0.00	1.00
16	1.00	0.89	0.00	1.00	0.00	1.00	1.00	0.00	0.92	0.00	0.00	1.00	1.00	0.85	1.00	1.00	0.00	0.00	1.00
17	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

1 In this table zero means no land is available and 1 means that the marginal and average productivities are equal.
2 Rows are AEZs from AEZ1 to AEZ18.
3 Columns are regions and regions are listed in Appendix B.

Source: Tyner et al. (2010). Regions and AEZ correspondence are described in the paper.

Besides the use of the TEM model to calculate the elasticity of crop yields with respect to area expansion, the only other attempt to estimate this parameter was documented in a letter from the Brazilian Sugarcane Industry Association (UNICA, 2009) addressed to CARB regarding its impressions and recommendation about the LCFS. In this letter, UNICA affirms that empirical data in Brazil suggests that crop yield elasticity with respect to area expansion should be around 0.9-0.95. To calculate this number they have separated new and traditional areas in Brazil according to the growth in planted area for crops in the time horizon from 2001 to 2007, based on microregional data, and compared the yields between these two types of area.

New Estimates of the Productivity of New Land vs Old Land in the United States

One of the crucial assumptions for the calculation of the LUC carbon intensity of biofuels is the so-called 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." 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 LUC intensity.

Figure 1 shows that since 2006, the prices of corn, soybeans, and wheat have risen dramatically. In response to stronger prices, aggregate crop acreage has increased in the United States. NASS reports acreage of principle crops. The average acreage over the 2004 to 2006 time period was 2.95 million acres lower than the average over 2007 to 2009 time period. Thus the 60 to 80%

increase in prices has led to about a 1% increase in acreage. Over the same two time periods, average corn ethanol production increased by more than 5 billion gallons.

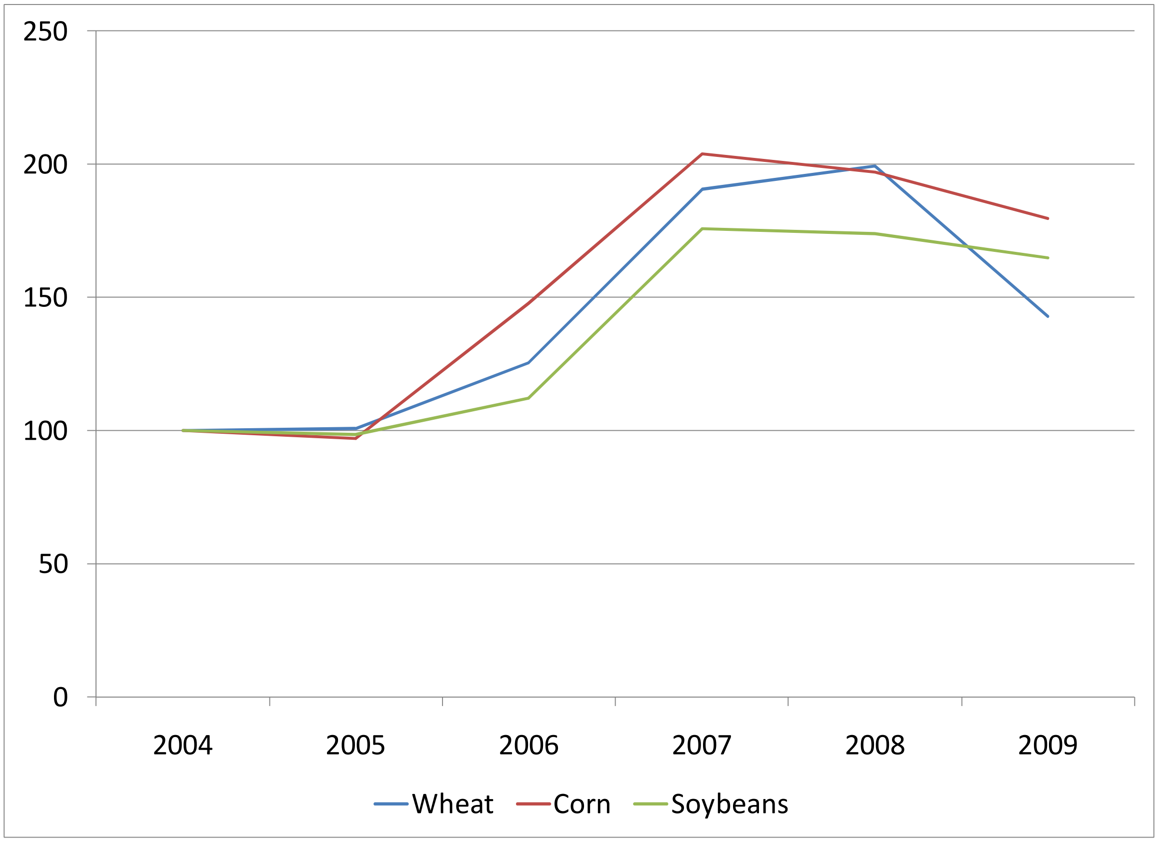

Figure 1. Index of Prices Received by U.S. Farmers for Corn, Soybeans, and Wheat (2004 = 100).

Figure 2 shows crop acreage of the top 15 (in terms of acreage) U.S. crops. From 2006 to 2009, crop acreage of these 15 crops increased by about 5 million acres. As shown, acreage is dominated by corn, soybeans and wheat, all of which showed an increase.

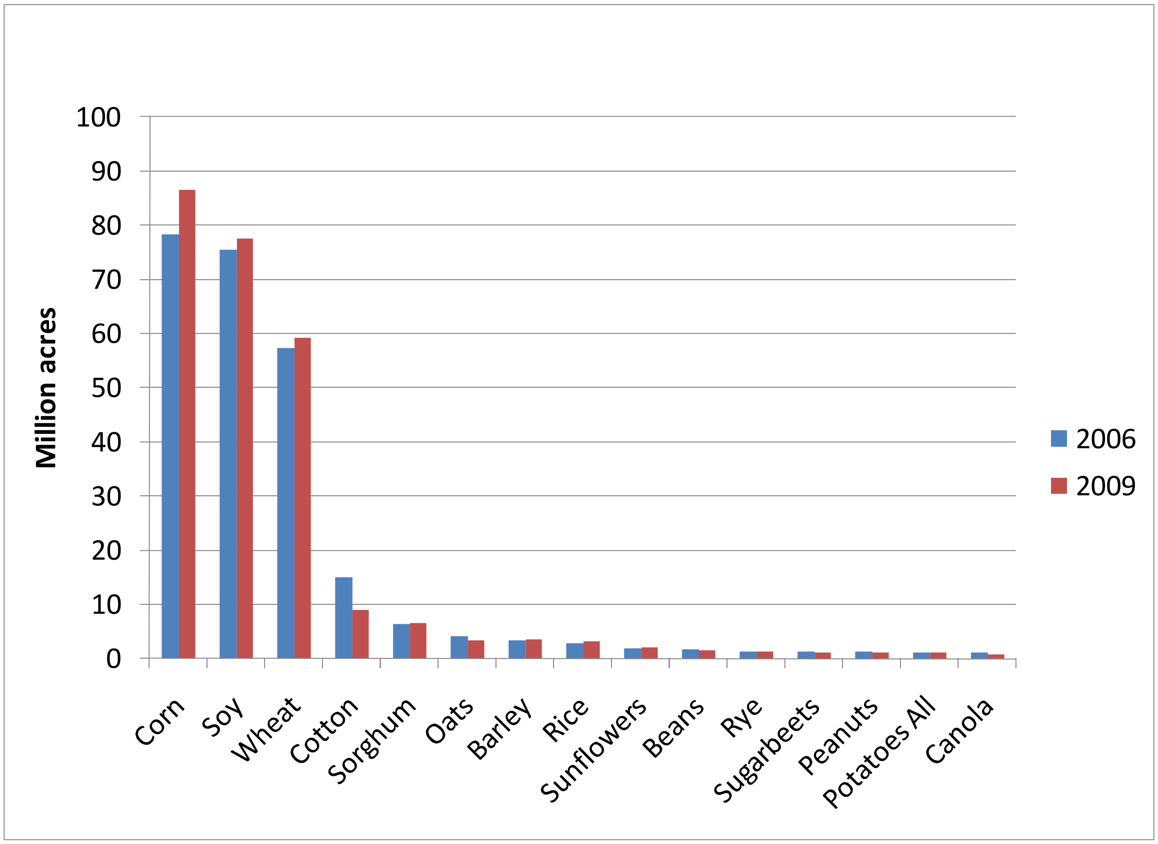

Figure 2. U.S. Crop acreage in 2006 and 2009

Figure 3 shows the change in acreage for states that showed the most change from 2006 to 2009. Perhaps not surprisingly, large agricultural states show the most change in acreage. The acreage decreases in North Dakota, Illinois and Indiana are likely due to adverse planting season weather that prevented farmers from entering their fields. Figure 4 presents the same data but on a percentage basis.

The data demonstrate that U.S. crop acreage expanded due to higher crop prices. This expansion should give some insight into whether crop yields in areas that expanded are higher or lower than crop yields in regions that were already being planted before the large increase in crop prices.

One method for determining the extent to which crop yields in expansion regions are lower than in regions that were previously planted would be to overlay the location of expansion regions on a soil and climate map and to determine any inherent difference in productivity. Due to limitations in time, resources, and expertise on our sub-group, an alternative method was devised.

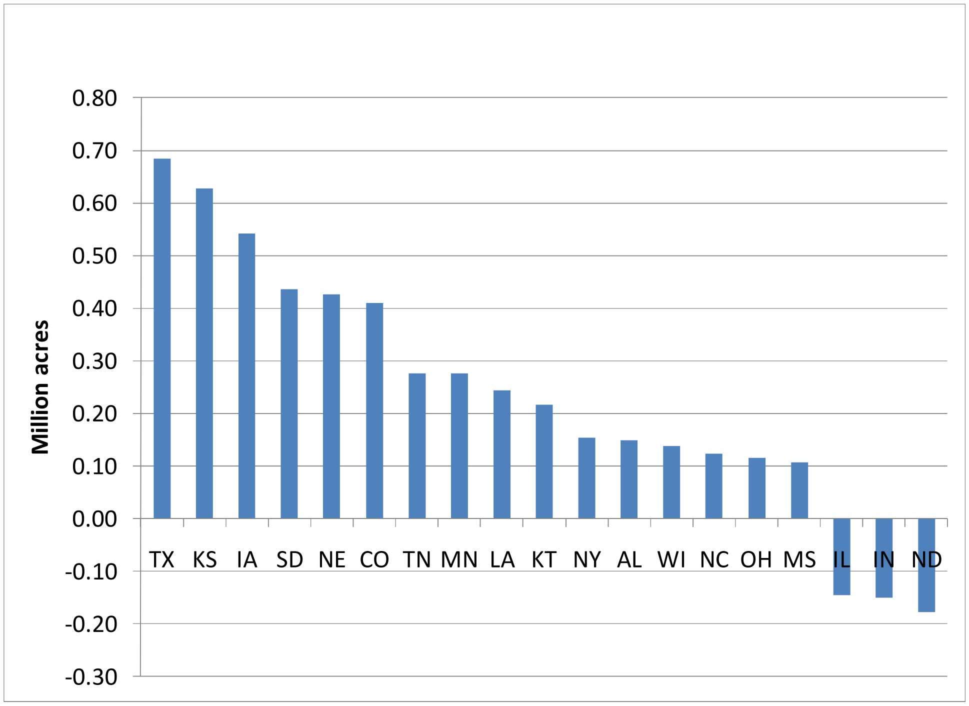

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Figure 3. State Level Change in Crop Acreage of 15 Top U.S. Crops

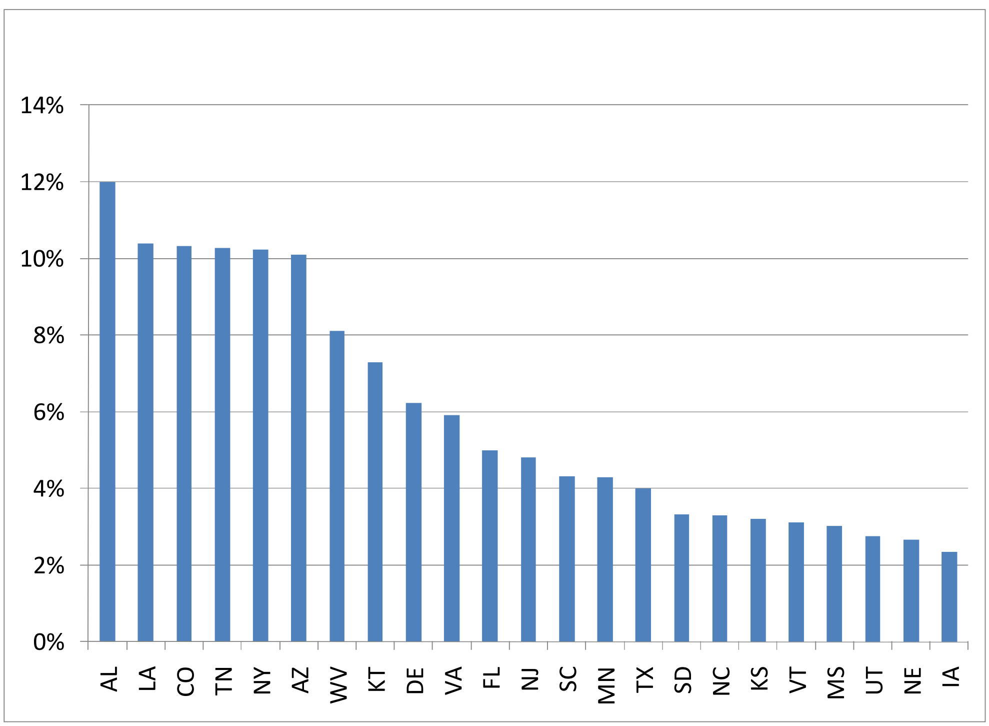


Figure 4. Percentage Change in Acreage of 15 Top Crops

A good metric of productivity of an area that is crop specific is the average crop yield in a region. If all areas that expanded crop acreage have lower average yields than areas that were previously planted, then we can say that land on which crop expansion occurred is less productive. Thus all one needs to do is to find the areas that expanded, estimate average crop yields in those regions, and compare the yield on expansion areas to the average yield that would have occurred had the expansion not taken place. This is a fairly straightforward exercise and we use NASS county data to make the calculations.

Data and Methods

Data of yield and planted area for each county was obtained from the National Agricultural Statistics Services (NASS) from 2000 to 2008 for the top 15 principal crops, which account for approximately 80% of total planted area for principal crops in the United States. The 15 crops are corn, soybeans, wheat, cotton, sorghum, oats, barley, rice, sunflower, beans dry edible, rye, sugar beets, peanuts for nuts, potatoes, and canola.[3] 2009 data for wheat has not yet been released by NASS so we only use the 2007 to 2008 time period to measure acreage expansion.

The first step is to measure crop yields for each county. To minimize the effects of weather variations, trend yields for each county were estimated for each crop and county. These trends were then used to estimate what yield would be in 2009. This 2009 trend for each crop is used to measure the crop-specific productivity of each county.[4]

The second step is to identify those counties where expansion occurred. This was accomplished by comparing average planted acreage of the 15 crops in 2007 and 2008, and comparing this acreage to average planted acreage in the period 2005 to 2006. If planted acreage in the latter period was higher, then the county is designated as an expansion county. Figures 1 and 2 show the change in acreage on both an acreage basis and a percentage change basis.

[3] Alfalfa is actually in the top 16 crops, but county level data for alfalfa is not available.

[4] Ideally more time would be spent collecting data from further back and to ensuring that all estimated trend yields give good estimates of productivity differences. But time and resource constraints being what they are, such an effort could not be done. Thus the county productivity measures reflect average growing conditions from 2000 to 2008 in each county and trend yields may be affected by yield outliers that occur either early or late in the sample period.

Figure 1 Percentage Change in Total Planted Acreage

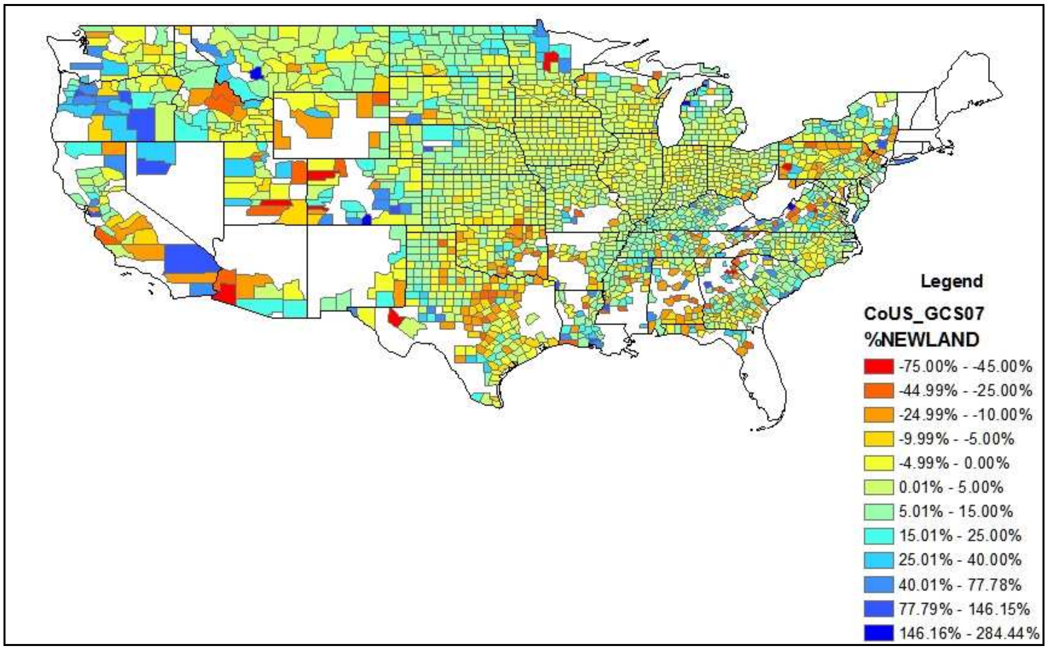
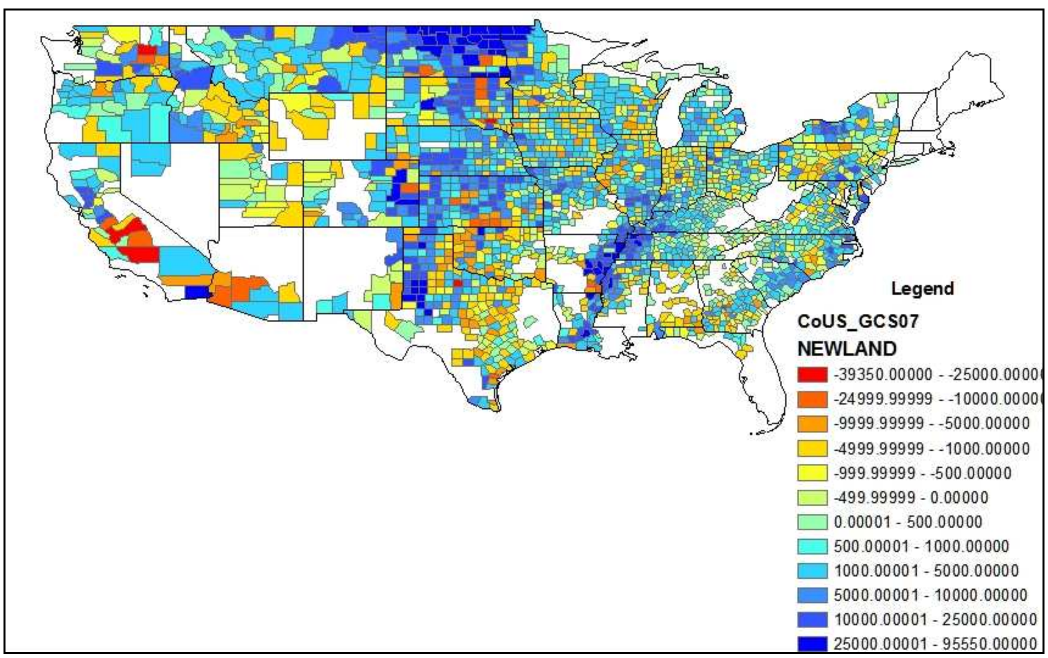


Figure 2 Change in Total Planted Acreage



Not all crops in expansion counties increased their acreage levels. We want to measure crop-specific productivity only for those crops that actually increased acreage in the expansion counties. Thus the next step was to identify those crops that increased acreage in each expansion county.

For those crops that increased in acreage in expansion counties, the 2009 trend yield for the county is taken as the yield that occurred on the expanded acreage. This may overstate the productivity of the land that was newly planted to the crop within a county, but this is as fine a geographic resolution that we will be able to obtain using county data.

The average yield for a crop across all expansion counties was estimated by weighting the 2009 trend yield for the crop in each county by the change in crop acreage in the county.

The average yield that would have occurred without expansion was estimated by weighting each 2009 county trend yield for the crop by the average planted acreage across 2005 and 2006. This measures what U.S. average yield would be in 2009 had acreage not changed.

The ratio of the average yield across all expansion counties to the average yield that would have occurred without expansion is an estimate of the elasticity of crop yields with respect to area expansion. The results are shown in Table 1.

Table 1. Results

Commodity	No Expansion Yield	Yield in Expansion Counties	Ratio
Wheat (bu)	40.5	49.8	1.23
Potatoes (cwt)	426.9	519.8	1.22
Peanuts (lbs)	3244.8	3622.6	1.12
Barley (bu)	60.3	63.4	1.05
Canola (lbs)	1537.3	1567.3	1.02
Rice (pounds)	7141.3	7014.0	0.98
Cotton (lbs)	914.3	886.4	0.97
Corn (bu)	158.7	151.4	0.95
Rye (bu)	19.3	18.0	0.93
Beans (lbs)	1726.7	1584.4	0.92
Sugarbeets (tons)	26.8	24.0	0.90
Sorghum(bu)	70.8	60.8	0.86
Oats (bu)	62.3	52.6	0.84
Soybeans (bu)	43.5	35.7	0.82

As shown, the results vary quite a bit across crops. On aggregate measure would be to weight the ratios by 2009 planted acreage. The resulting weighted average is 0.98.

Conclusion and Recommendation

From the papers identified in the literature review we conclude that the current knowledge about the GTAP parameter "elasticity of crop yields with respect to area expansion" is limited. CARB and most of the applications of the GTAP model simply assumed an arbitrary value for such parameter, without scientific knowledge behind it. We identified three attempts to better identify the crop yield response to are expansion. The first one is an econometric approach to test the hypothesis that area expansion lowers yields (Babcock and Carriquiry, 2010). Although this approach does not estimate a value for the elasticity of crop yields with respect to area expansion, it suggests the CARB assumption is not reasonable for one region of the model where most of the land changes are happening. Another attempt to deal with such a parameter compared the yields in new agricultural areas with yields in traditional agricultural regions in Brazil. Although it is a simple approach, it suggests that the elasticity of crop yields with respect to area expansion is 0.9 (UNICA, 2009),which is much higher number than the 0.5 central value used by CARB. Finally, the most sophisticated approach was performed by the GTAP group itself (Tyner et al., 2010). They have used a biogeochemistry based ecosystem model to estimate the potential crop yields in each AEZ and used it to update the study of carbon emissions related to the US corn ethanol program.

New estimates provided in this report for the United States suggests that the elasticity varies across crops, which makes sense because of the large shifting in U.S. crops that occurs. The minimum elasticity estimated was 0.82 for U.S. soybeans, which again is much higher than the estimates used by CARB in their previous analysis. The maximum value of the elasticity is 1.23 for wheat, which suggests that the net effect of shifting wheat acreage was to push wheat into areas of higher yields. Weighting the crop specific elasticities by 2009 planted acreage gives an overall average of 0.98. However, it is not clear that this type of weighted average offers much meaning.

The three studies reviewed plus the new estimates provided for the United States are strongly suggestive that yields on new lands in Brazil and the United States are much closer to yields on existing land. In particular, the numbers from the TEM model used by Tyner et al. (2010) represent a much better approach than the number previously used by CARB and they are available for use. The data for the U.S. also suggest that the yield ratio varies by crop, which the GTAP model can accommodate.

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