Using GTAP's Yield Elasticity with Respect to Price to Capture Production from Double Cropping

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Before expanding into new area, it is expected that producers explore increasing the productivity of their land in response to higher returns. 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 other forms of intensification avaiable to producers in many areas of the world, namely multi-cropping. This is somewhat surpsiring because one of the first farmer responses to higher crop prices is an increase is 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 1 shows that the number of acres of double cropped soybeans increased substantially in 2007 and 2008 in response to higher crop prices.

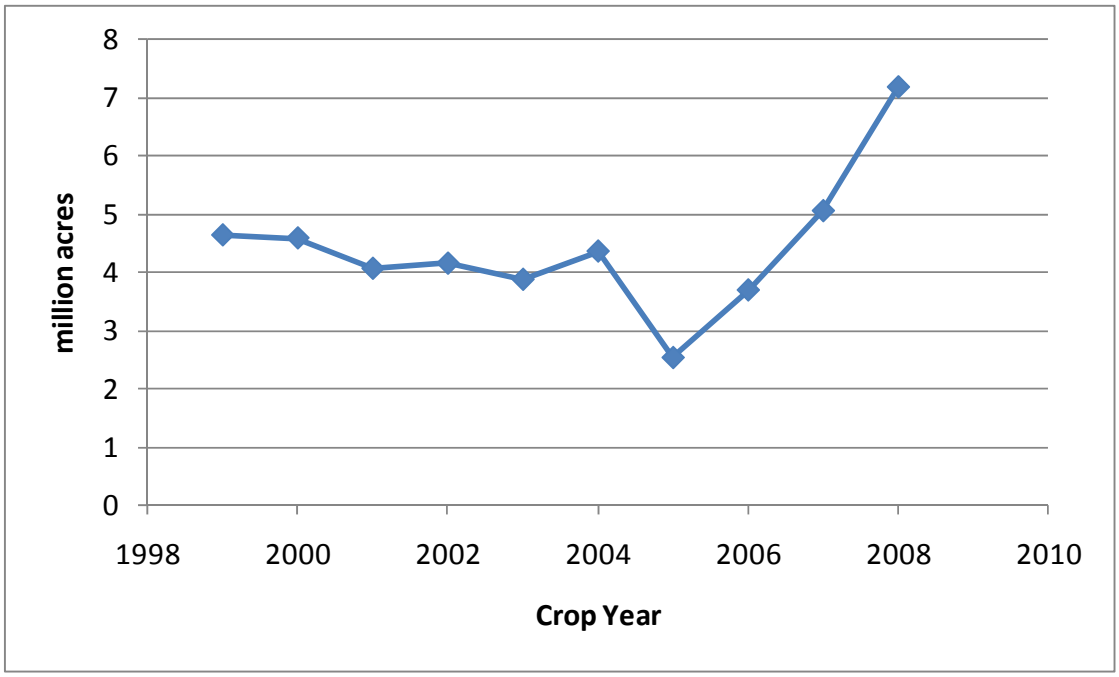

Figure 1. Number of Double Cropped Soybean Acres in the United States
Source: FAPRI Agricultural Outlook

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 2 shows that total Brazilian safrinha has increased substantially over the last 15 years.

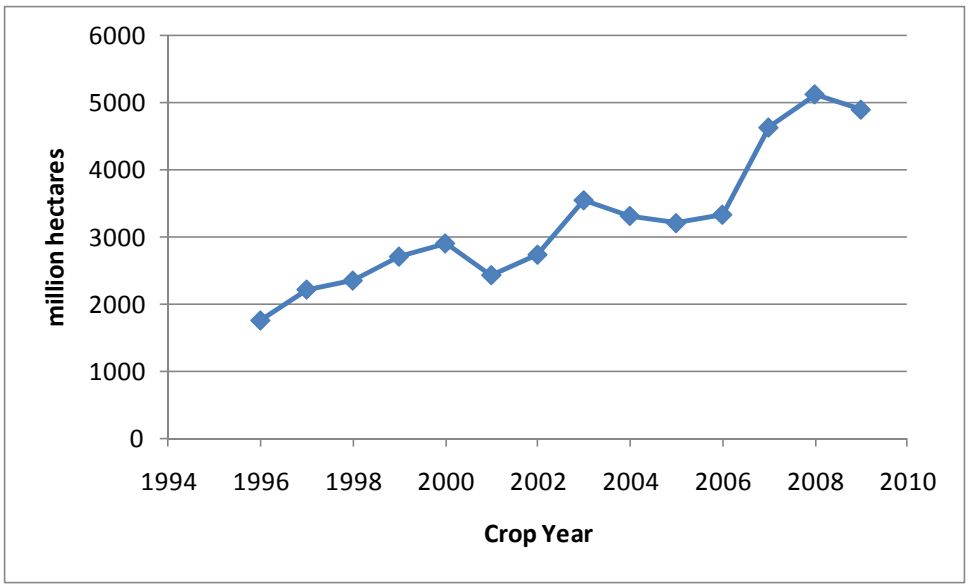

Figure 2. Safrinha (Double Cropped Corn) Land in Brazil
Source: FAPRI Agricultural Outlook

If all safrinha corn is on land used for the main summer crop (usually soybeans), output expands without the need of new land 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 3 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 to properly account 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.

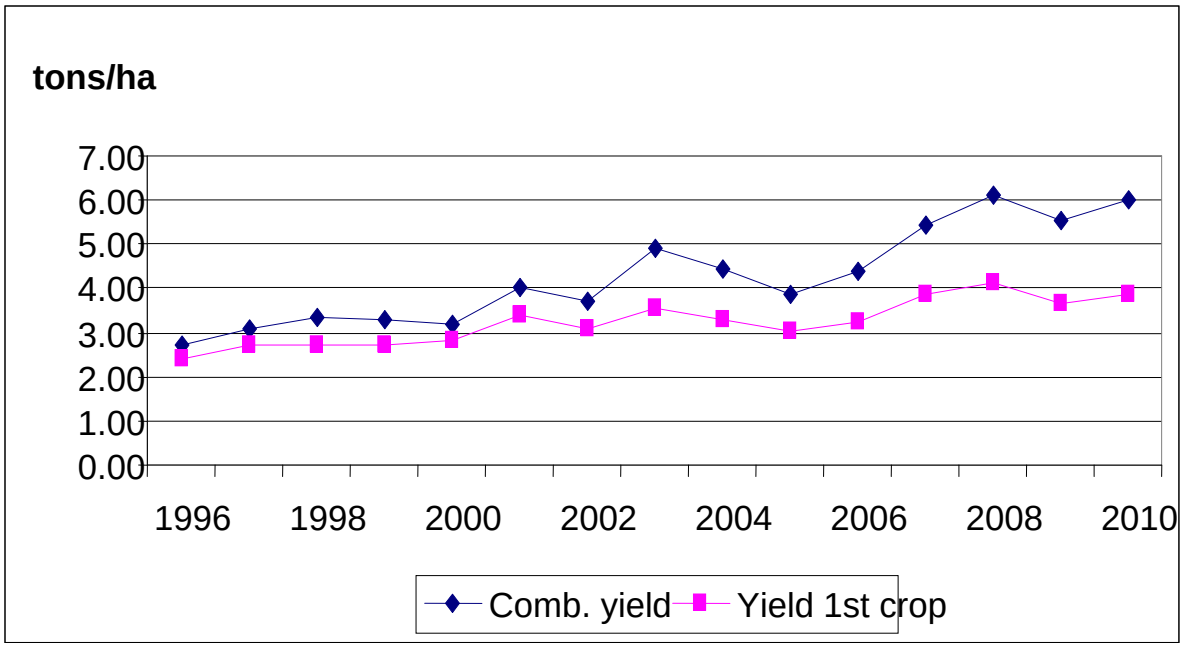

Figure 3. Corn yields for the first crop and the implied combined yield

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

$$Y = \frac{Q}{A_1 + A_2}; \quad Q = A_1 Y_1 + A_2 Y_2 \tag{1}$$

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:

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

which implies

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

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:

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

where the share of production is denoted by *s*.[1] This expression makes it clear that the yield elasticity with respect to price measures changes in both 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 equation (1), 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 by 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:

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

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

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

[1] 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.

and the only difference between the current GTAP elasticity and the adjusted elasticity that accounts for the additional production form double cropped acreage is $s_2\eta_{A_2,P}$. Notice that the only difference in the adjustment factor 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 4 uses this yield difference and FAPRI's estimate of total double cropped acres to calculate shares from 2000 to 2008.

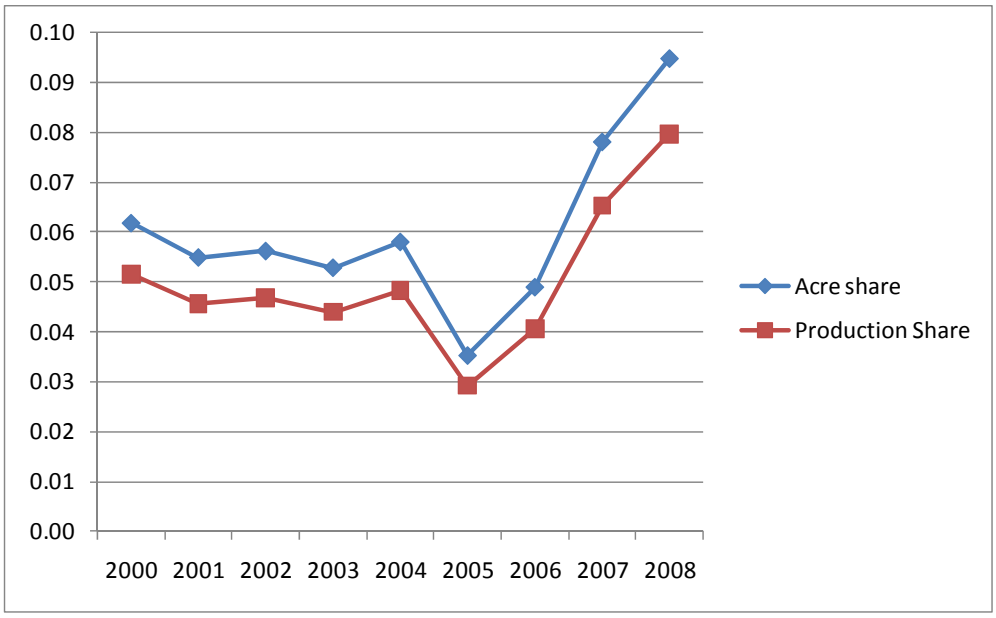

Figure 4. Share of Double Cropped Acres

The remaining step is to calculate the elasticity of double cropped acres with respect to price. Figure 5 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 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 percent 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 Figure 4 in 2007 and 2008 is likely associated with a decrease in the elasticity the actual amount of adjustment is not likely to differ by much across years.

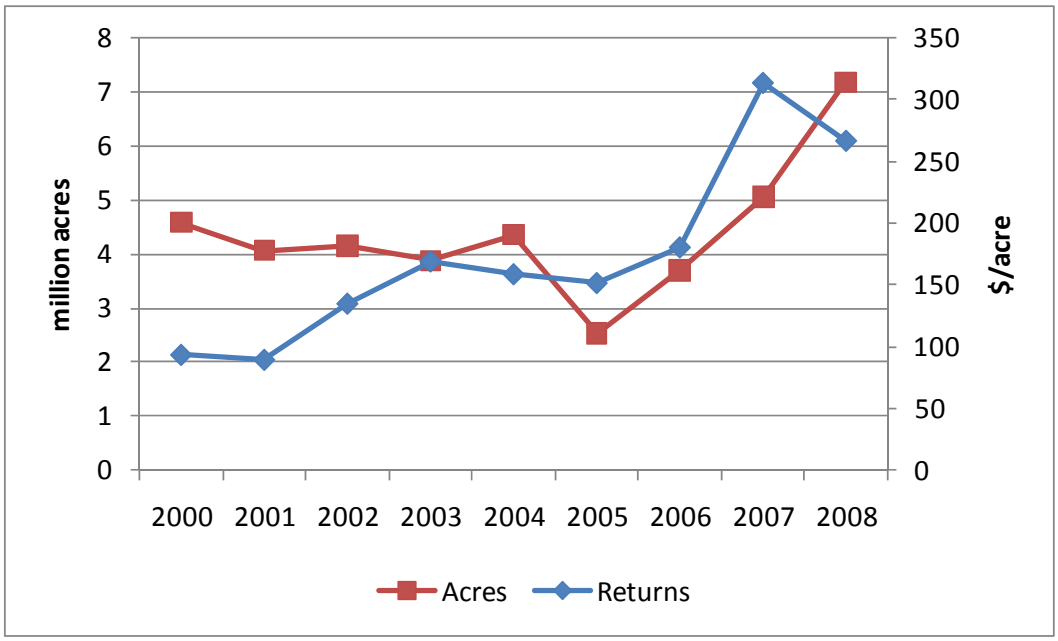

Figure 5. Comparing U.S. Double Cropped Acres and Soybean Returns

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 above 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 analysis is on soybeans, it makes sense to account for the extra production from double cropping as accruing to land planted soybean land that is not double cropped.

Second cropped 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 6. A share of 20% seems reasonable to use to calculate the adjustment factor. There was a 150% increase in double cropping from 2004-2006 relative to 2007-2009 periods. This was associated with an increase in the profitability of growing the second crop of corn. 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. Thus 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.

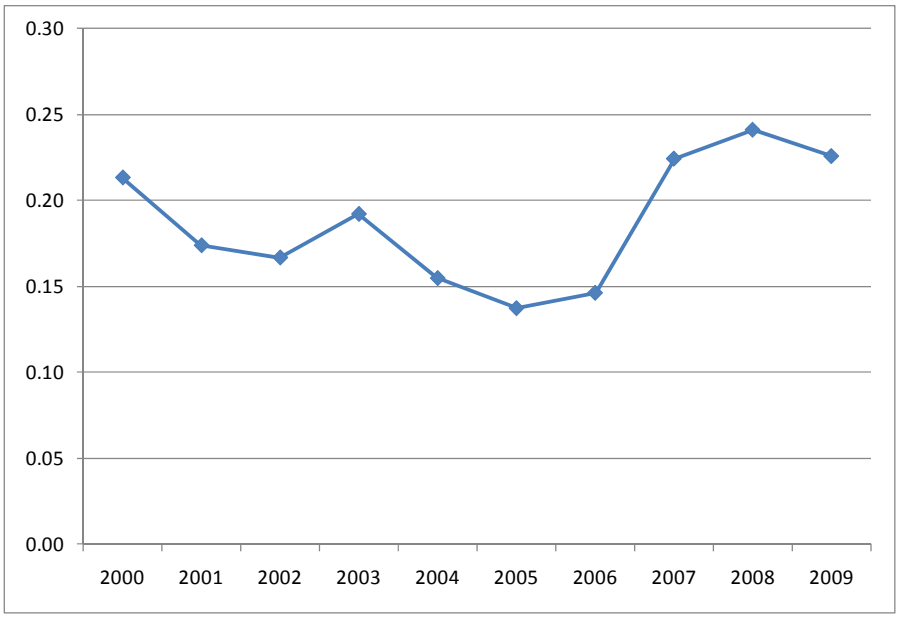

Figure 6. Share of Brazilian Soybeans Grown in Double Cropping System

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, soybeans are 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.