

## Analytical Framework for Modeling Acreage Response

The theoretical underpinning of supply response assumes that producers wish to maximize expected net returns, the difference between expected market revenue and variable costs of production. Based on the firm's implicit, multiproduct production function, it can be shown that the supply of a farm commodity is a function of output and input prices for that commodity, as well as output and input prices for competing crops (Willott and others).

This study utilizes State-level NFA data from 1991-95 to estimate regional supply response. For each program crop (except rice), acreage response on NFA is analyzed for major production regions. All acreage response equations within a region are treated as a system of acreage allocation decisions, similar to the equations estimated by Holt. Effects of imposing theoretical constraints—symmetry and linear homogeneity—were then considered.<sup>9</sup> These constraints are derived from a theoretical framework developed by Barten and Vanlout that allocates land input among crops to maximize profit, subject to a total land constraint. For purposes of illustration, let's assume a system based on a hypothetical situation in the Midwest which contains acreage share equations for corn, soybeans, and wheat as follows:

$$S_c = a_{11} + b_{11} \text{NRT}_c + b_{12} \text{NRT}_s + b_{13} \text{NRT}_w$$

$$S_s = a_{21} + b_{21} \text{NRT}_c + b_{22} \text{NRT}_s + b_{23} \text{NRT}_w$$

$$S_w = a_{31} + b_{31} \text{NRT}_c + b_{32} \text{NRT}_s + b_{33} \text{NRT}_w$$

where  $S_c$  = the percentage of the program crop NFA planted to corn,

$S_s$  = the percentage of the program crop NFA planted to soybeans,

$S_w$  = the percentage of the program crop NFA planted to wheat,

<sup>9</sup>The symmetry restriction requires that cross-net return regression coefficients across the share equations be equal, while the linear homogeneity constraint requires that the sum of all own- and cross-return regression coefficients in each of the equations be zero. The symmetry restriction reflects the notion that the cross-price elasticities are linked to the ratios of the acreage shares and expected revenues between two competing crops. The linear homogeneity constraint reflects the fact that the share of a program crop's NFA is homogenous of degree zero in prices, since the same proportional change in net returns for the program crop and competing crops does not alter the share of the program crop NFA planted to a specific crop.

$\text{NRT}_c$  = expected net returns (\$/ac.) for corn,

$\text{NRT}_s$  = expected net returns (\$/ac.) for soybeans, and

$\text{NRT}_w$  = expected net returns (\$/ac.) for wheat.

The symmetry restriction requires that cross-net return coefficients across the equations be equal, that is,  $b_{21} = b_{12}$ ,  $b_{31} = b_{13}$ , and  $b_{32} = b_{23}$ . This means that, for example, the percentage point change in corn acreage associated with a 1-unit change in expected soybean net returns equals the percentage point change in soybean acreage associated with a 1-unit change in expected corn net returns.

In addition, the linear homogeneity constraint requires that

$$\begin{aligned} b_{13} &= -(b_{11} + b_{12}) \\ b_{23} &= -(b_{21} + b_{22}) \\ b_{33} &= -(b_{31} + b_{32}) \end{aligned}$$

In other words, the sum of all own- and cross-return coefficients in each of the three equations must be zero. This simply reflects the fact that the profit function is linear homogenous in output and input prices, which, intuitively, means that net returns would increase by the same proportion if both output and input prices increase by a fixed proportion. The share of the program crop NFA, however, is homogenous of degree zero in prices, since the same proportional changes in net returns for the program crop and competing crops will not alter the share of NFA planted to a specific crop.

Acreage responses on the program crop NFA are estimated by Seemingly Unrelated Regressions (SUR) as a system, which is asymptotically equivalent to maximum likelihood. The acreage response associated with a farm commodity is a function of expected net returns for the primary and competing crops, as illustrated in the previous equations and estimated in the following section. In cases where imposing either of the theoretical constraints worsened or did not substantially change the regression results, acreage response equations without that theoretical constraint are used in this report.

## Supply Response Estimates on NFA

Supply response on program crops' NFA is estimated for major program crops (except rice) for the North Central, Central and Northern Plains, Southern Plains, Southeast, and Delta regions.<sup>10</sup> Farmers' use of NFA for a program crop is estimated by pooling time-series (1991-95) with cross-section (individual States in the region) data. As an illustration, this section focuses on supply response on corn NFA in the North Central region, which includes eight States (Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin). This region accounts for about two-thirds of U.S. corn production. The time series are based on farmers' use of corn NFA in 1991-95, when planting decisions were free of restrictions and were based solely on market incentives. The pooling provides 40 observations (5 years multiplied by eight States), which sufficiently overcomes the degrees-of-freedom problem.

Planting corn NFA to corn, to soybeans, or leaving it idle were the three most important uses of corn NFA in the North Central region. During 1991-95, these three uses accounted for 92 percent of total corn NFA in the region: 54 percent for planting to corn, 33 percent for planting to soybeans, and 5 percent for leaving NFA idle. The remaining 8 percent of NFA was planted to other program crops, minor oilseeds, sorghum, or other crops. Farmers' use of corn NFA was treated as a system of land allocation decisions in this study, encompassing corn NFA planted to corn, soybeans, other crops, or left idle. This illustration reports only the estimates of corn NFA planted to corn and soybeans.

### Supply Response Estimates: Model I

We used two modeling approaches, designed to address issues related to using NFA data for estimation. In the first model (Model I), the dependent variable is specified as the percent of corn NFA planted to corn or soybeans. Explanatory variables include expected net returns for corn and soybeans, as well as a set of intercept dummies for seven of the eight States in the region. Because the corn-soybean crop rotation is common in the North Central region, producers are reluctant to plant NFA to alternative crops, unless the switching of plantings brings an increase in profits that exceeds the potential benefit of the crop rotation.<sup>11</sup> Expected net returns equal the expected price times the

trend yield by State, minus variable cash costs of production for the North Central region. The expected prices are derived from the December corn futures price and the November soybean futures price at the Chicago Board of Trade in mid-March, the time when planting decisions are made for corn. Expected prices are further adjusted by a State-specific, 5-year average basis (the difference between the futures prices and cash prices received by farmers in the delivery month of the futures), thus arriving at a farm-level equivalent price. The trend yield is estimated using data from 1975-95. The two equations are estimated by Seemingly Unrelated Regression (SUR) with theoretical constraints—symmetry and linear homogeneity—imposed, and yield the following estimation results:

(1) Percentage of corn NFA planted to corn:

$$\begin{aligned} \%NFACR = & 51.580 + 0.336 \text{ ERTCR} - 0.324 \text{ ERTSOY} \\ & (21.53) \quad (4.63) \quad (-4.53) \\ & - 0.012 \text{ ERTWH} + 6.075 \text{ D1} + 5.807 \text{ D2} \\ & (-1.54) \quad (1.67) \quad (1.81) \\ & + 16.135 \text{ D3} - 1.886 \text{ D4} + 16.333 \text{ D5} \\ & (4.89) \quad (-0.60) \quad (5.15) \\ & + 2.718 \text{ D6} - 2.478 \text{ D7} \\ & (0.82) \quad (-0.77) \end{aligned}$$

(2) Percentage of corn NFA planted to soybeans:

$$\begin{aligned} \%NFASOY = & 19.489 - 0.324 \text{ ERTCR} \\ & (10.31) \quad (-4.53) \\ & + 0.324 \text{ ERTSOY} + 17.423 \text{ D1} + 16.964 \text{ D2} \\ & (3.92) \quad (5.85) \quad (6.79) \\ & + 6.906 \text{ D3} + 8.168 \text{ D4} + 4.121 \text{ D5} \\ & (2.67) \quad (3.41) \quad (1.68) \\ & + 9.945 \text{ D6} + 18.867 \text{ D7} \\ & (3.78) \quad (7.47) \end{aligned}$$

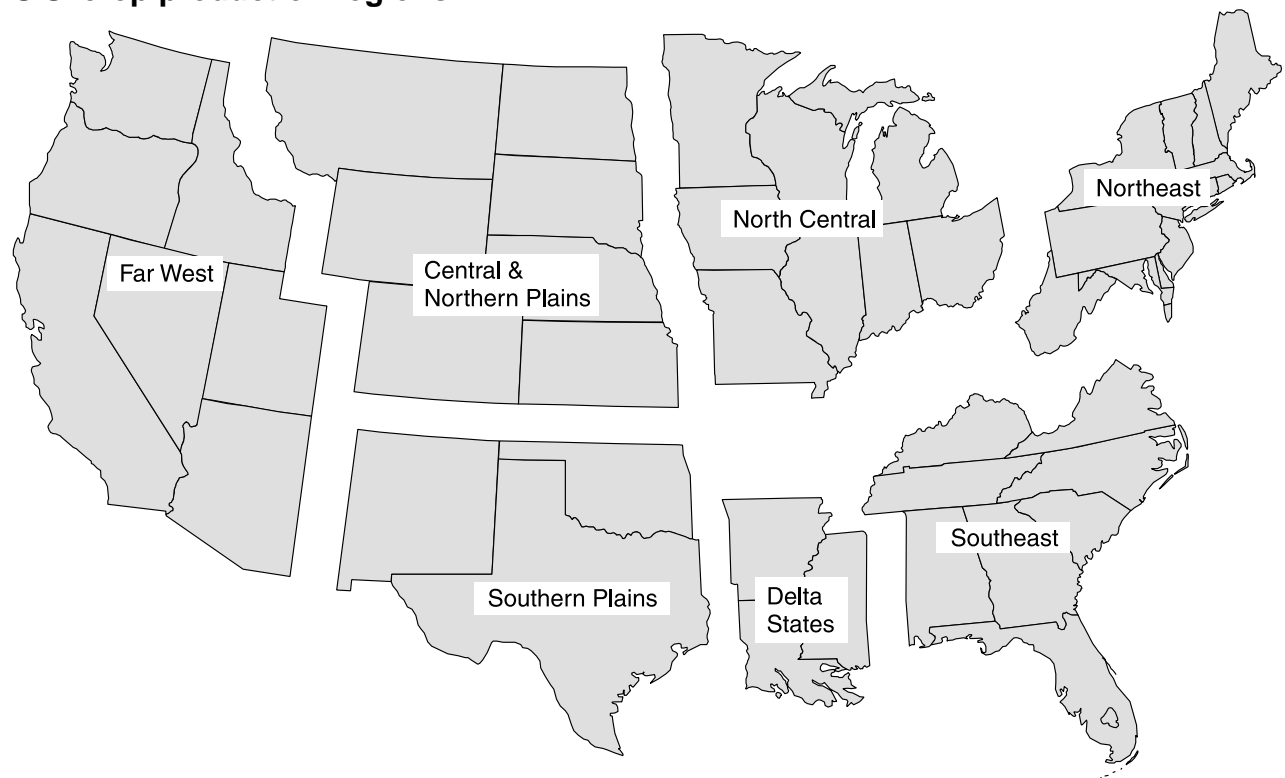
where  $\%NFACR$  = percentage of corn NFA planted to corn  
 $\%NFASOY$  = percentage of corn NFA planted to soybeans

<sup>11</sup>In 1995, corn-soybean rotations accounted for about one-half of crop-land planted to corn (USDA, 1996a). Crop rotation tends to result in an increase in corn yields following the rotation crop (most commonly soybeans), as insects and diseases are less of a problem with corn-soybean rotations, relative to continuous corn operations. To a large degree, the effect of crop rotations is reflected in producers' expected net returns.

<sup>10</sup>The production regions are defined in figure 2.

Figure 2

## U.S. crop production regions



- ERTCR = expected net returns for corn per acre
- ERTSOY = expected net returns for soybeans per acre
- ERTWH = expected net returns for wheat per acre

D1 through D7 are State dummies for Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Ohio, respectively, leaving Wisconsin as the “base” State. The figures in parentheses are t-ratios. All expected net returns variables and many State dummies are statistically significant at either the 1- or 5-percent level of significance.

Estimated regression results from Model I are shown by commodity and by production region in appendix tables 1-7. The regression equations are estimated by SUR, which does not significantly alter regression coefficients from those estimated by OLS, due to the use of a small sample size, but does increase t-ratios in some cases.

Imposing the theoretical restrictions in the estimation of acreage response on NFA generally improves the regression results for the North Central and the Central

and Northern Plains regions. For example, regression results without these restrictions show that the wheat expected net returns variable has a positive sign and statistically significant (with a t-ratio of 2.17) effect on soybean planted acreage in the North Central region—an unexpected result that contradicts the expectation of a negative coefficient because winter wheat competes with soybeans in this region. Imposing theoretical restrictions does not resolve the sign problem for the wheat net returns variable, but makes the regression coefficient less than statistically significant (with a t-ratio of 1.6), which is then excluded in the soybean acreage response equation in this region (appendix table 6). Imposing the theoretical restrictions also raises t-ratios for several explanatory variables in the Central and Northern Plains region.

With few exceptions (sorghum and barley in the Central and Northern Plains), most of the expected net returns variables for the program crop itself show a positive sign and are statistically significant at the 5-percent level of significance (with t-ratios greater than 2.0). Nearly all of the regression coefficients for competing crops have the expected negative sign, and many of them are statistically significant at the 5-per-

cent level of significance. However, in the Southeast and Delta regions, the soybean expected net returns variable has a positive sign in the wheat acreage equation, suggesting that higher expected soybean net returns would lead to greater wheat seedings, due to a common practice of soybeans-wheat double cropping in these regions (appendix table 1).

**Percent NFA Planted as Dependent Variable Provides Lower Bound Estimates**

Specifying the dependent variable in the acreage response equation as the percent of NFA planted to corn may result in measurement problems relative to the underlying acreage shifts. Differences in the planted acreage covered by NFA associated with the change in ARP levels in the sample period introduce a downward bias (see explanation below) into the estimated own-price coefficient, suggesting that the corresponding elasticities derived from the previous model specification represent lower bounds (Westcott, 1997). The illustrations below provide examples of how this bias can occur for hypothetical farming situations, which would then have similar effects for the statistical measures used in the aggregate analysis.

To illustrate this potential for underestimating supply response, a representative farm with a 100-acre corn base is assumed. With a 0-percent ARP, the NFA covers the 86th through the 100th acre, the last 15 acres

of the corn base (fig. 3). If we examine those acres more closely in figure 4, we can assume that in the first year the farmer chooses to plant corn on 94 acres of the 100-acre corn base. This represents 9 acres of the 15 normal flex acres or 60 percent of the NFA. Assume further that, in the following year, price expectations are lower, so the farmer adjusted plantings downward to 91 acres (fig. 4). With no change in the ARP, these plantings represent 6 acres of the 15 normal flex acres or 40 percent of the NFA. Thus, the year-to-year change in the percent of NFA planted measures the farmer’s reduction in plantings. However, if prices are lower in the second year, a more restrictive ARP may have been implemented to assist in reducing large supplies. If we assume that a 5-percent ARP had been in place for the second year, normal flex acreage has shifted to reflect the ARP requirement, and now covers the 81st through 95th acre (fig. 5).

Because the farmer plants 91 acres in this example, the ARP is not restricting his or her planting of corn. However, these plantings now include 11 acres of NFA, representing 73 percent of the NFA (fig. 6). In this case, the producer’s decision to lower plantings in response to lower prices is measured as an increase in the percent of NFA planted—from 60 percent to 73 percent. The effects of varying ARP levels on the calculation of the percent-NFA measure can result, as shown in this example, in an increase in this vari-

Figure 3  
**Supply function--Normal flex acres (NFA) with a 0-percent Acreage Reduction Program**

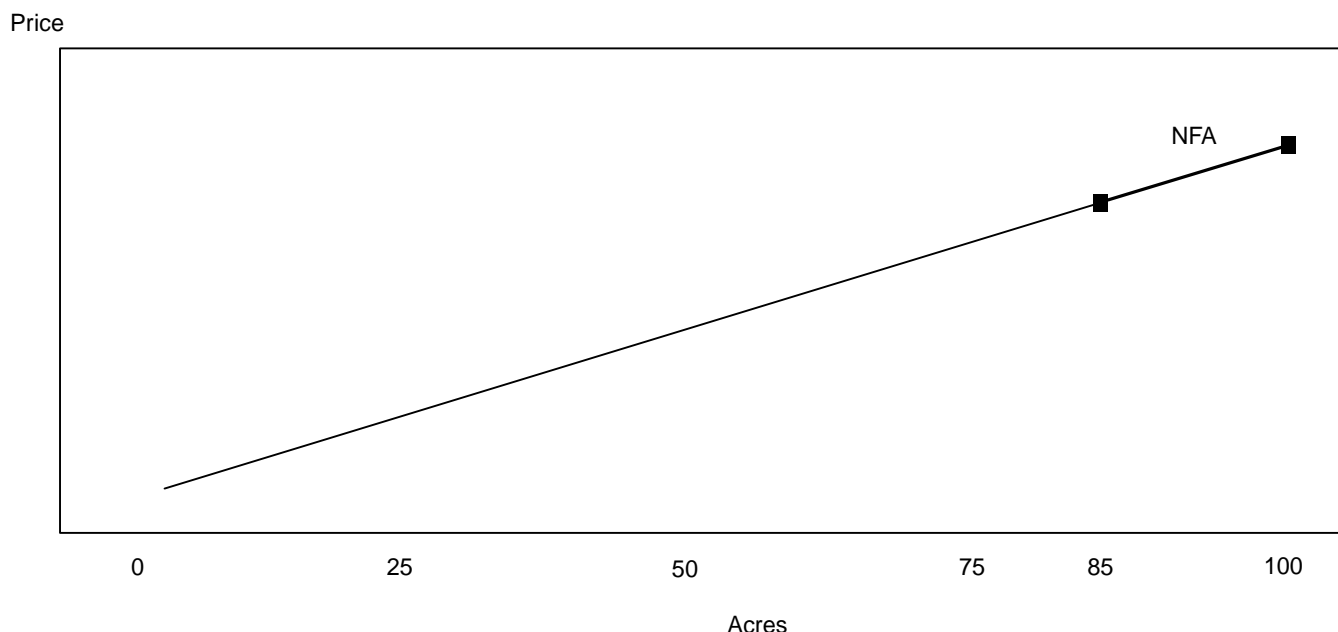
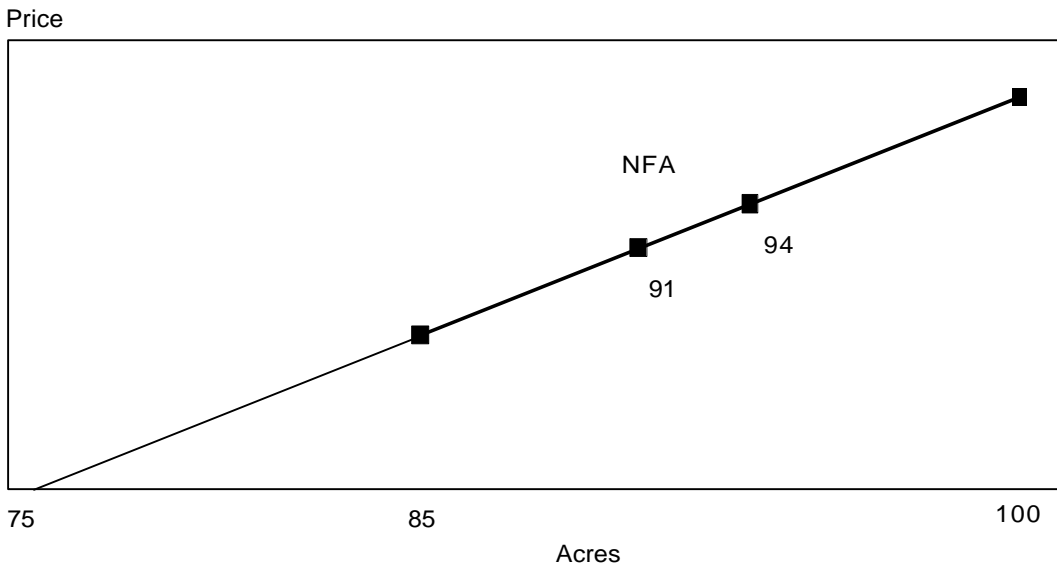


Figure 4  
**Supply function--Normal flex acres (NFA) planting examples,  
 0-percent Acreage Reduction Program**



NFA examples

- ▶ First year, 94 acres are planted; 9 acres are NFA. This represents 60 percent of NFA.
- ▶ Second year, 91 acres are planted; 6 acres are NFA. This represents 40 percent of NFA.

Figure 5  
**Supply function--Normal flex acres (NFA) with a 5-percent Acreage Reduction Program**

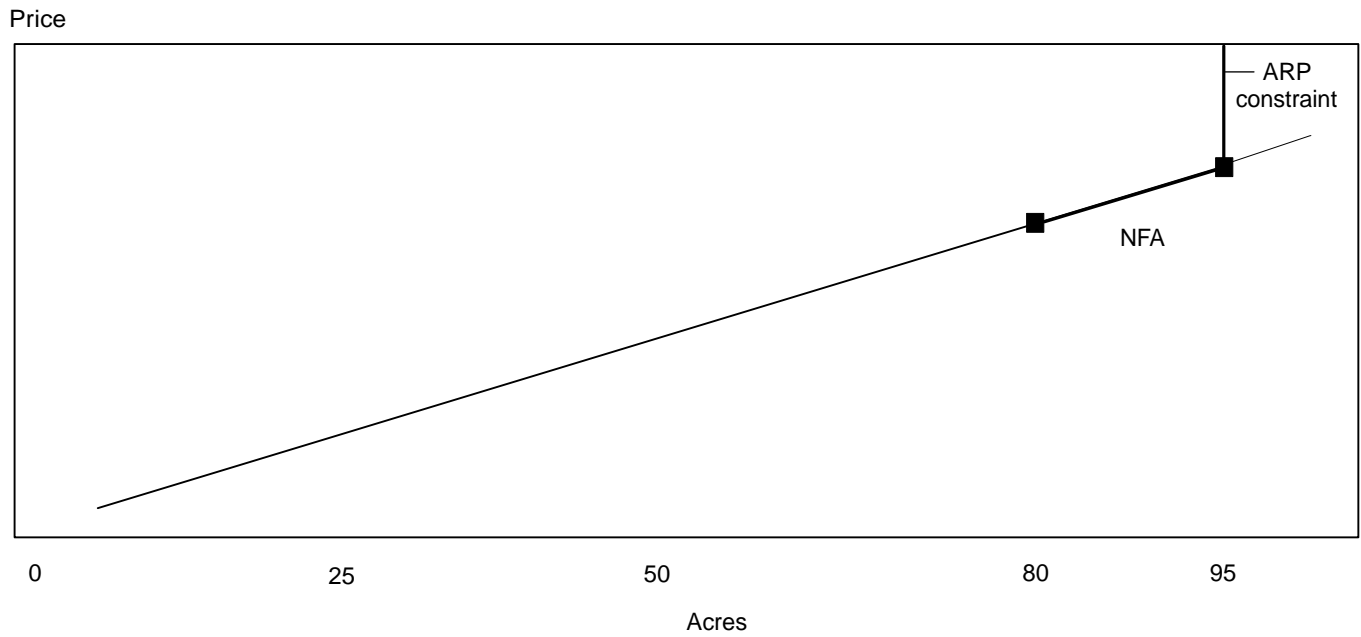
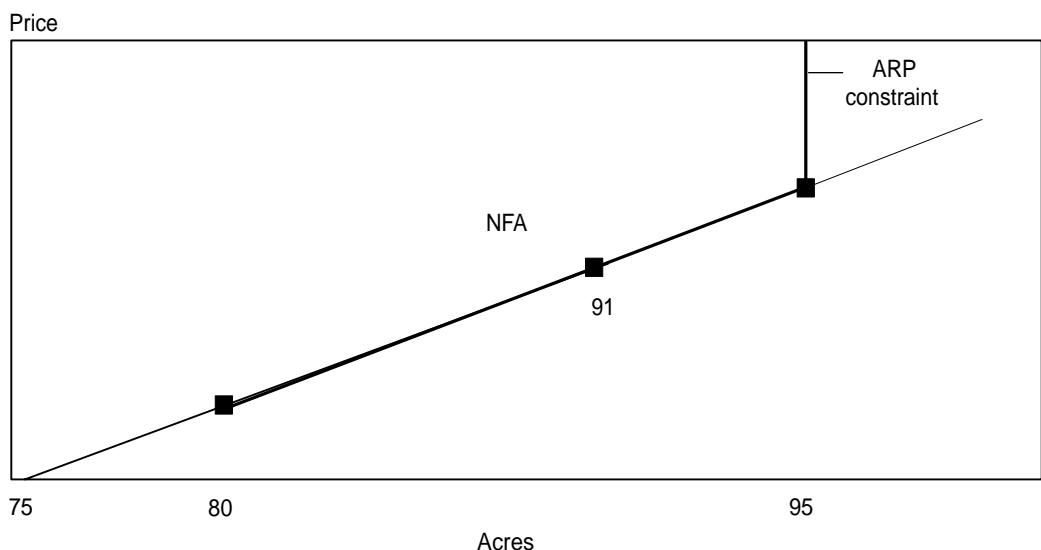


Figure 6  
**Supply function--Normal flex acres (NFA) planting examples,  
 5-percent Acreage Reduction Program**



NFA examples

- ▶ With a 5-percent ARP assumed for the second year, NFA has shifted down to cover acres 81 to 95
- ▶ Second year plantings of 91 acres are now 11 acres of NFA. This represents 73 percent of NFA.

able—even when plantings actually fell in total on that farm (from 94 to 91 acres in this example). This effect diminishes the positive relationship between price and acreage and results in a downward bias in the elasticity estimate, suggesting that the implied elasticity should be interpreted as a lower bound.

**Supply Response Estimates: Model II**

In the second model (Model II), an alternative dependent variable, defined as the percent of the combined NFA and ARP acreage, is used to derive estimates which have an upward bias, providing an upper bound (explained below). Together, results from Model I and Model II give a range for the elasticities under investigation.

The lower bound interpretation of estimates from Model I, using the dependent variable of percent NFA planted, results from interaction of NFA acreage with the year-specific ARP. A possible adjustment to address this concern is to incorporate the ARP into the dependent variable. One way to do this is to define the dependent variable as the percentage of the combined NFA plus ARP land that was planted. The percentage of combined corn NFA and ARP planted to corn (%NFAARPCR) in the acreage response equation, based on this specification, is estimated as follows:

$$\%NFAARPCR = 36.027 + 0.255 \text{ ERTCR}$$

(9.95) (4.68)

$$\begin{aligned}
 & - 0.215 \text{ ERTSOY} - 0.040 \text{ ERTWH} \\
 & \quad (-3.65) \quad \quad (-1.34) \\
 & + 3.696 \text{ D1} + 3.664 \text{ D2} \\
 & \quad (0.75) \quad \quad (0.77) \\
 & + 10.126 \text{ D3} - 0.639 \text{ D4} \\
 & \quad (2.04) \quad \quad (-0.14) \\
 & + 11.467 \text{ D5} + 2.751 \text{ D6} - 1.948 \text{ D7} \\
 & \quad (2.41) \quad \quad (0.58) \quad \quad (-0.41)
 \end{aligned}$$

Expected net returns are, again, based on futures prices adjusted for the basis at the State level. All variables were defined earlier.

This alternative reduces the downward bias described earlier, but does not fully eliminate it. It also adds a policy-related upward bias to the measurement of acreage shifts, as described below.

**Alternative Dependent Variable (Model II) Provides Upper Bound Estimates**

To illustrate the upward bias resulting from Model II, we again use the representative farm with a 100-acre corn base. With a 0-percent ARP, NFA covers the 86th through the 100th acre. If we assume the producer plants the full 100-acre base, 15 normal flex acres are planted, which represent 100 percent of the combined NFA plus ARP acreage (fig.7). If we again assume

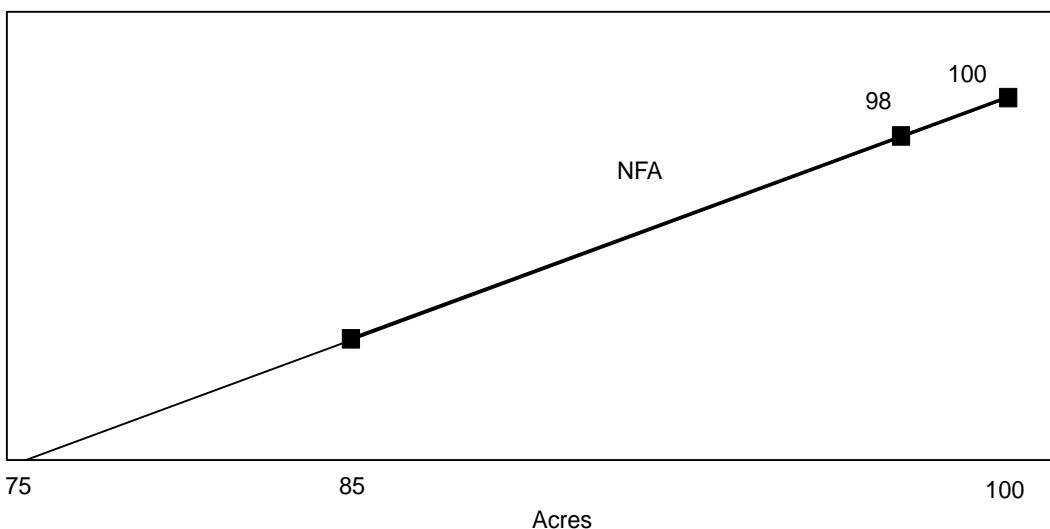
that price expectations for the following year are lower, the farmer may adjust plantings downward to, for example, 98 acres as also shown in figure 7. With no change in the ARP, these plantings represent 13 acres of the 15 normal flex acres, or 87 percent of the combined NFA plus ARP acreage. The year-to-year change in the percent of NFA plus ARP planted (13 percent in this example) measures the farmer's reduction in plantings.

If, however, the assumed lower prices for the second year led to an increase in the ARP, dependent variable measurement problems arise again. An ARP increase to 5 percent moves the NFA down to cover the 81st to the 95th acre (fig. 8). The 5-percent ARP prohibits the producer from planting the 98 acres that would be allowed with a 0-percent ARP while still remaining within program rules. Instead, 5 acres must be idled as a condition for program participation, and 95 acres are planted to corn. All 15 normal flex acres are planted and these plantings represent 75 percent of the

Figure 7

**Supply function--Additional normal flex acres (NFA) planting examples, 0-percent Acreage Reduction Program**

Price



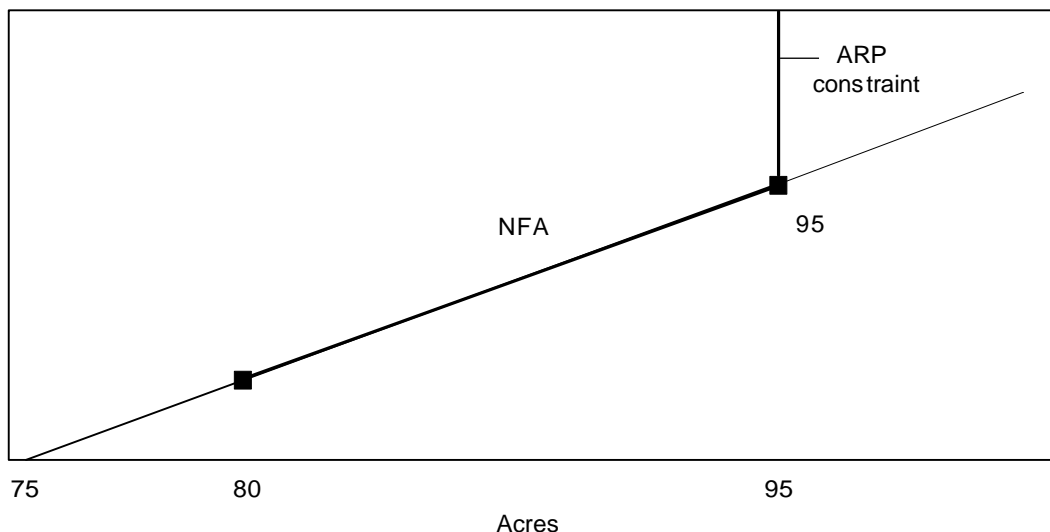
NFA examples

- ▶ First year, 100 acres are planted; 15 acres are NFA. This represents 100 percent of (NFA + ARP).
- ▶ Second year 98 acres are planted; 13 acres are NFA. This represents 87 percent of (NFA + ARP).

Figure 8

**Supply function--Additional normal flex acres (NFA) planting examples, 5-percent Acreage Reduction Program**

Price



NFA examples

- ▶ With a 5-percent ARP assumed for the second year, NFA has shifted down to cover acres 81 to 95.
- ▶ Producer must idle five acres to participate.
- ▶ Second year plantings are now 95 acres; 15 acres are NFA. This represents 75 percent of (NFA + ARP).

combined NFA plus ARP acreage. This reduction from 100 percent of the combined NFA, plus ARP acreage to 75 percent of the combined NFA plus ARP acreage, overstates the producer's response to price. Some of the measured acreage shift results from the change in the ARP, but would be attributed to price in the model estimation. Thus, model estimates using this dependent variable should be viewed as providing an upper bound.

Estimated regression results from Model II (upper bound) also are shown by commodity and by production region in appendix tables 1-7. As for Model I, Model II regression equations are estimated by SUR. Again, imposing the theoretical restrictions in the estimation of acreage response on NFA generally improves the regression results for the North Central and Central and Northern Plains regions. For example, regression results without these restrictions show that the soybean expected net returns variable has a positive sign and highly significant (with a t-ratio of 13.29) effect on corn plantings in the North Central region—a result of multicollinearity between corn and soybean expected net returns (with a correlation coefficient of 0.87). Without imposing theoretical restrictions, one might drop the soybean expected net returns variable, which would ignore the strong competition for cropland use between the two principal crops in this region. However, imposing the restrictions produces a

coefficient for the soybean net returns variable which not only has a negative sign (as expected), but also is statistically significant (with a t-ratio of -3.65). In addition, with the restrictions, the coefficient of the wheat net returns variable has a negative sign and is modestly significant (with a t-ratio of -1.34) in the corn NFA acreage response equation. Without the restrictions, the variable has an unexpected positive sign, but is not statistically significant (with a t-ratio of 0.71).

With few exceptions (sorghum and barley in the Central and Northern Plains), most of the expected net returns variables for the program crop itself result in positive signs that are statistically significant (with t-ratios greater than 2.0). All of the regression coefficients for competing crops have the expected negative sign, and many are statistically significant.

Relative to Model I, regression coefficients in Model II are typically larger, suggesting that acreage price elasticities estimated from Model II would be on the high side (upper bound). For example, the coefficient for the wheat net returns variable in the wheat NFA acreage response equation in the Central and Northern Plains region is estimated to be 0.359 from Model II, which is higher than the 0.147 estimated from Model I (appendix table 1).