Wheat Acreage Supply Response in the United States

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The dynamic structure of wheat acreage supply response is considerably more
complex than previous studies have recognized. The distributed lag response is saw-
toothed in its pattern, which is believed to eminate from the influence of summer
fallow in crop rotations in the Great Plains. The acreage response elasticity estimate
for the Great Plains at mean price was 1.3, and for the aggregate U.S. it was 1.5. For
the United States, the proportion of long-run response experienced over the first five
years from an increment to price was .24, .44, .70, .95, and .99.

Key words: wheat acreage response, distributed lags, latent state variables, crop
rotations, government programs.

Quantification of supply response to price in
agricultural commodities has been a challenge
for agricultural economists since the early days
of regression analysis. In the post-World War
II period, difficulties have been particularly se-
vere because of the sporadic and ever-changing
government programs for the major commod-
ities such as corn and wheat. Yet, many areas
of research in our profession require quanti-
tative measures of supply response, e.g., the
commodity storage models so popular in the
late 1970s. Government programs, which his-
torically have been an obstacle to precise sta-
tistical estimation from time-series data, re-
quire good estimates of supply response in
order to measure their effectiveness in meeting
policy makers' goals.

  Wheat is by far the most important food
crop grown in the United States, and only corn
and soybeans are more valuable field crops.
Obtaining a reliable quantitative estimate of
wheat acreage supply response, including its
dynamic structure, is an important and chal-
lenging research problem. The relatively few

periods without government controls, and the
frequent changes in the structure of these con-
trols, complicates an already difficult task. The
objective of this study is to estimate empiri-
cally this dynamic response function and to
evaluate carefully the robustness of the spec-
ification through the use of recursive residuals
and scrutinizing the specification for any sen-
sitive aspects (Leamer).

  The approach taken is relatively empirical,
in that elementary economic theory is used as
a guide to the specification but no rigid a priori
hypotheses are imposed. The model is for-
mulated so that a large family of hypotheses
on specific structure are encompassed within
the single framework, particularly with respect
to the dynamic response (Mizon). Of course,
this general philosophy is severely limited by
the few degrees of freedom available in annual
time series under changing government pro-
grams.

  The next section examines some of the spe-
cial problems in the specification of wheat
acreage response, particularly under dry land
farming conditions in the Great Plains which
introduce complex dynamic considerations.
The empirical model is presented in the second
section, and the primary statistical results are
given in the third. In the fourth section, alter-
native specifications are evaluated to further
validate the model; a brief summary and con-
clusions section is given at the end.

Modeling Wheat Supply Response

The Nerlove partial adjustment/adaptive expectations model of supply behavior has dominated dynamic specification in agricultural supply studies (Nerlove). Eckstein recently developed a rational expectations model which is observationally equivalent in its reduced form to the Nerlove model (Eckstein 1984, 1985). This theoretical contribution provides insights into the idealized consistency which a supply model should have, but it is not clear how useful this simple model is for empirical quantification. Taylor's results on stochastic duality theory of the firm demonstrate how short-run supply and factor demand equations will contain state variables associated with quasi-fixed factors of production (Taylor). Therefore, a complete model of the firm's long-run output supply equation would contain a system of dynamic equations to describe the firm's investment behavior with respect to quasi-fixed factors, but data are rarely available to model these investment equations.

The practical alternative is to recognize the omission of these state variables and try to allow for their effects through a more general distributed lag response on the explanatory variables included in the regression equations. If the latent state variables tend to change rather smoothly over time in the aggregate data used for estimation, this approach should work quite well, especially if the state variables respond primarily to the set of explanatory variables needed in a static supply equation (output and factor prices). Completely ignoring these latent state variables and focusing only on price expectations as the source of dynamic behavior in supply is likely to cause serious specification errors in the distributed lag response.

In general, an important source of latent state variables is the dynamics of crop rotations (Eckstein). The complementarity in joint production, such as with corn and soybeans in the Corn Belt or wheat and barley in the Northern Great Plains, comes from sequencing the crops to control various pests (including weeds) and improve soil structure and fertility. Typically, expected net returns per acre from one of the crops in the rotation is greater than for the other, but the secondary crop is the next best source of income that will break the life cycle of pests on the primary crop. If the price of the primary crop rises, farmers will temporar-ily plant more acres of it relative to the secondary crop, but the resulting increased population of pests (or depleted nutrients in the soil) will provide a large incentive to get more acres into the secondary crop the following year. Some of these effects may require a distributed lag response in the explanatory variables, price of the primary crop in particular, and part of the effects are likely to surface as negative autocorrelation in the regression residuals.

In the semiarid climate of the Great Plains, summer fallow plays the same role as a secondary crop as described above. A year with summer fallow is very effective for weed control, especially perennials; it breaks the life cycle of many crop diseases; soil moisture is stored for the following crop; and various nutrients, especially nitrogen, are released with the accelerated decay of organic matter. Although all income is sacrificed during the fallow year, the variable costs are low compared to producing a crop. Much wheat acreage expansion and contraction in the Great Plains is associated with the relative frequency of summer fallow, especially in the climatic transition areas where summer fallowing is a marginal practice. During policy control years, increased frequency of summer fallow is an effective way for farmers to meet the acreage diversion requirements and increase average yields per acre.

Another source of latent state variables is the firm's capital stocks. It might be tempting to assume that averaging across firms in aggregate data would remove the need to allow for changing levels of capital stocks. The cyclical nature of livestock breeding stocks in the aggregate is well known, but machinery capital also tends to fluctuate widely too. Purchases are clustered in time because farmers' current income levels influence replacement and new purchase decisions. The opportunity cost of liquid assets is less during good times, and the progressive income tax encourages more purchases in high income years. Actual machinery services available change more than the quantity of stocks would suggest because newer stocks incorporate later technology and thus more input capacity per unit time.

The aggregate amount of machinery services available is particularly important for wheat acreage response in the Great Plains because it imposes a constraint on farmers' ability to respond opportunistically to fluctuations in prices. The large reserve of actual or potential summer fallow acres provides an unusual op-

portunity for quick increases or decreases in seeded acreage as expected returns fluctuate when machinery services are plentiful.

Another major source of expanded crop acreage in the Great Plains is rangeland, and wheat is the primary crop at the extensive margin. Asymmetries in the costs of such land use changes are large because it is difficult to reestablish livestock range. This situation tends to make wheat acreage changes at the extensive margin occur relatively slowly in response to price fluctuations.

Several conclusions are apparent from the above discussion of latent state variables in wheat acreage response, particularly under a semiarid climate. First, aggregate data will not be available to permit the inclusion of these state variables directly in a regression equation for acreage response. But even if data were available, the model would need to be expanded to include a behavioral equation for each state variable which conditioned short-run response or else one could not estimate long-run acreage response to wheat price. Second, the distributed lag structure will need to be estimated from the sample data. Care must be exercised in any smoothing of the lag distribution because the influence of summer fallow is likely to yield an irregular structure, maybe exhibiting a sawtooth pattern.

In regard to the synergetic relationship between the primary and secondary crops, acreage response of the primary crop to price of the secondary crop might very well be positive with a net substitution into or out of a third crop (range in the Great Plains). Consequently, it is presumptuous for researchers to deflate price of the primary crop with that of an alternative crop which is frequently grown in the same region.

In using economic theory to guide specification of the acreage response regression equation, there should be a careful weighing of the benefits of using a priori knowledge against the consequences of imposing a too-restrictive model dictated by the theory. Our static theory of the firm is quite general, but the dynamic theory available tends to be very restrictive, e.g., the recent model of Eckstein. The specification problem is further removed from our theory because at a given point in time aggregate data reflect extreme heterogeneity in land and climatic resources as well as firm size, fixed stock of labor, and capital resources. This elementary observation suggests that a good deal

of flexibility should be allowed in the empirical model. It would seem naive to attempt a specification which was restrictive enough to partition out a price expectations hypothesis separately from the effects of latent state variables associated with production.

The strategy used in this study was to let static theory of the firm suggest a general structure for the implied equilibrium of the dynamic time-series regression equation. The dynamic structure was assumed to be an unknown distributed lag response in all independent variables of the regression. Specifically, the static model has wheat acreage as a general function of wheat and alternative crop prices, prices of farm inputs, and government policy variables, which are defined in the next section.

Empirical Model

The basic economic variables, functional form, and dynamic structure are given in the next subsection. Then a brief description of the government program variables is given and their role in the model is explained. Additional detail on the rationale and definitions of the program variables are provided in the appendix along with some generalizations which were not statistically significant.

Economic Variables and Structure

A semilog functional form was used to force a declining price elasticity (inversely proportional to acreage), which would be expected as a result of the finite amount of arable land. Commodity prices were deflated by the index of prices paid by farmers for production items (1977 base). A general rational lag approximation was used as a guide to choosing a dynamic specification. The lag structure turned out to be rather irregular at lags up to four years and then declined geometrically at a rapid rate.

Acreage in year t refers to the calendar year in which harvest takes place for spring wheat planted that spring and winter wheat planted the previous fall. Separate price variables enter the acreage response equation for September in year $t - 1$ (March of year t in North Dakota) and for crop years $t - 2$, $t - 3$, and $t - 4$; these prices are the average received by farmers. Crop year $t - 2$ starts in July of year $t - 2$

and ends with June of year $t - 1$. March price in year t is used for North Dakota because most of the wheat acreage is in spring wheat. September price is viewed as the latest information used by winter wheat farmers to formulate their price expectations for the following harvest, but September price is not necessarily expected price per se because lagged seasonal prices are also in the equation. No attempt is made to partition out an expected price formation mechanism from the effects of latent state variables which might be measured by lagged prices.

State prices were weighted by production and averaged to get a wheat price for the Great Plains. However, the national price was used in the evaluation of alternative crops—feed grains and "feed grains and hay" price indices—because the close substitution among feed grains for livestock feed makes the correlation in prices among the components extremely high. One complication with wheat acreage response is that one of the most important alternative crops is forage (livestock range in the Great Plains), for which a good measure of price is wanting. Therefore, it should be no surprise if the price of other crops is not statistically significant.

The problem of supply response measurement from prices of alternative crops is exacerbated by the tendency for all grain (including wheat) prices to move in the same direction, especially when the price changes are large. Results reported in such studies as this one with only one commodity price in the equation must be interpreted according to the structure of the data from which statistical estimation was done. These results for wheat acreage would not be appropriate if there were major shifts in regional production of the alternative crops or if the relative price of wheat to one of the alternative crops were to change substantially from the range within the sample data used here. The static *ceteris paribus* assumption in the interpretation of an empirical price elasticity must be relaxed; instead of "all other prices held constant," it is "all other prices are following similar time paths relative to that for wheat as existed in the sample period." This is a weak result, but all that the data base can support; or put another way, all that the implicit experimental design matrix of the dynamic regression can support.

The final model after empirically identifying the distributed lag structure is

$$(1) \quad \begin{aligned} A_t = {} & \beta_0 + \beta_1 \log SP_{t-1} + \beta_2 \log P_{t-2} \\ & + \beta_3 \log P_{t-3} + \beta_4 \log P_{t-4} \\ & + \beta_5 \log FP_{t-1} + (\textit{policy variable terms}) \\ & + \lambda E(A_{t-1}) + u_t, \end{aligned}$$

where SP, P, and FP are September wheat, seasonal wheat, and feed grain prices, respectively; A is acres of wheat seeded; and $E(A_{t-1})$ is the lagged expectation of the regression equation. This latter term imposes a geometric lag on all explanatory variables in the equation. The $\{\beta_i\}$ and λ are unknown parameters, and u_t is the disturbance term which is assumed to follow an autoregressive/moving average (ARMA) process.

The a priori restrictions on parameters suggested by economic theory are $\beta_1 + \beta_2 + \beta_3 + \beta_4 > 0$ and $0 \le \lambda < 1$. The former implies a positive long-run acreage response to wheat price, while the latter yields a stable dynamic response equation. The sign of β_5 is indeterminate for reasons discussed earlier in relation to crop rotations. The ARMA process for u_t is assumed stable and invertible in the moving-average components.

In an equilibrium state where commodity prices and production costs have been constant for an extended period and there are no government programs, the expected value of the dynamic response in (1) reduces to (written as a deterministic equation):

$$(2) \quad A = \gamma_0 + \gamma_1 \log P + \gamma_2 \log FP,$$

where $\gamma_1 = (\beta_1 + \beta_2 + \beta_3 + \beta_4)/(1 - \lambda)$ and $\gamma_2 = \beta_5/(1 - \lambda)$. Wheat price denoted by P in the steady state ignores the seasonal variation structure of September price compared to the crop-year price. If the seasonality were multiplicative (additive in logs), it would simply make an adjustment to γ_0. The intercept is $\gamma_0 = (\beta_0 + \text{constant})/(1 - \lambda)$, where the constant reflects the "no allotment dummy variable" defined in table 1 as well as the seasonality for September price.

Government Program Variables

Since the 1950s, federal wheat programs have moved away from mandatory controls in favor of voluntary provisions relying on economic incentives to encourage participation. However, the overall intent of these programs—to maintain prices above a certain lower limit or floor and to minimize massive stockpiling of excess supplies—has remained constant. For a

succinct summary of the various farm programs for wheat, the reader is referred to Houck et al. Additional detail is available in Hadwiger.

Earlier quantitative studies used a variety of approaches to model "policy variables" to account for the influence of government programs designed to control planted acreage (Blakeslee; Garst and Miller; Hoffman; Houck et al.; Lidman and Bawden; Morzuch, Weaver, and Helmberger). One popular device for incorporating policy changes with a minimum of extra explanatory variables is the concept of effective payment per bushel associated with a program option, such as guaranteed loans and acreage diversions. This approach was first applied to wheat acreage by Hoffman at the regional level, and shortly after by Houck et al. at an aggregate level for the United States. The method used by Lidman and Bawden stems from the same line of thought, but focuses on an expected price concept defined by the adaptive expectations mechanism which incorporates the government guaranteed loan rate jointly with market price last period.

An alternative method for modeling policy changes which expends more degrees of freedom was introduced by Garst and Miller. They used a more complete set of program variables in place of the effective payment variables used by Hoffman and Houck et al. But as noted by Morzuch, Weaver, and Helmberger, their use of actual acres diverted from wheat through the diversion and set-aside programs raises questions about joint dependencies in the statistical model; all uses of acreage are simultaneously determined in response to the market and government incentives. Morzuch, Weaver, and Helmberger partitioned the sample into marketing quota and nonquota years under the hypothesis that the quota years (1954–63) had such tight restrictions on acreage that market price had essentially no influence on plantings. They also included 1950 and 1964 in those years of no price response.

In this study, government program features are broken into seven key variables which are summarized in table 1. The allotment variable represents an upper bound on total wheat plantings for program participants during the years it was in effect. This variable was set at zero in the years when the allotment was not in force, and a dummy variable was introduced to allow the intercept to shift in these years (third column, table 1). The national allotment

variable was used in the Great Plains model because adjustments in this variable were so nearly proportional among farms.

The marketing quota dummy allows for a shift in the intercept during the tight restrictions on marketings and acreage during 1954–63. Two separate methods were used and compared. The first, which will be referred to as the "quota model," assigned zero to wheat prices during the quota years and used the marketing quota dummy variable in table 1 to adjust the intercept. In the distributed lag framework used, all lagged prices during the quota years were set at zero, but the lagged prices associated with the quota period which appeared in the regression equation immediately after the quota period were not set at zero. The second method, called the "dummy model," simply assigned ten individual year dummy variables during the quota years and made no adjustment in prices. The separate year dummy variables completely remove the influence of the quota years on parameter estimates except for parameters in the disturbance structure.

The acreage reserve years under the Soil Bank program (1956–58) were treated as unique with a separate dummy varible for each year. Participation rates were low during 1956 and 1958, which suggested that these years might not be significant. The conservation reserve portion of the Soil Bank program was not specifically entered as a separate variable.

Marketing certificate payments were intended to provide an incentive for program participation between 1963 and 1973. In reality, they served as an increment to the average price received by wheat farmers. Results are reported later which support this conclusion. The average certificate value per bushel of all wheat produced in the previous crop year was added to the September price of wheat and added to the contemporaneous crop year price. The 49¢ deficiency payment per bushel of production in 1977 was treated as a marketing certificate payment.

A diversion dummy variable was introduced for the years 1962–66 and 1969–70 to shift the intercept on the acreage equation downward, thus reflecting the incentives of program provisions during those years. The set-aside dummy variable in table 1 performs the same role for 1971–73, and it is assumed that the deficiency payment/set-aside program in 1977 could be approximated by treating it

Table 1. Annual Federal Wheat Program Variables

Year	Allotment (1000 acres)	No. Allotment	Mktg. Quota	Acreage Reserve 1956	Acreage Reserve 1957	Acreage Reserve 1958	Certif. Payments ($/bu.)	Diver-sion[d]	Set-Aside[e]
1945	0	1	0	0	0	0	0	0	0
1946	0	1	0	0	0	0	0	0	0
1947	0	1	0	0	0	0	0	0	0
1948	0	1	0	0	0	0	0	0	0
1949	0	1	0	0	0	0	0	0	0
1950	72,800	0	0	0	0	0	0	0	0
1951	72,800[a]	0	0	0	0	0	0	0	0
1952	0	1	0	0	0	0	0	0	0
1953	0	1	0	0	0	0	0	0	0
1954	62,800	0	1	0	0	0	0	0	0
1955	55,800	0	1	0	0	0	0	0	0
1956	55,000	0	1	1	0	0	0	0	0
1957	55,000	0	1	0	1	0	0	0	0
1958	55,000	0	1	0	0	1	0	0	0
1959	55,000	0	1	0	0	0	0	0	0
1960	55,000	0	1	0	0	0	0	0	0
1961	55,000	0	1	0	0	0	0	0	0
1962	49,500	0	1	0	0	0	0	1	0
1963	55,000	0	1	0	0	0	.18	1	0
1964	53,200	0	0	0	0	0	.43	1	0
1965	53,300	0	0	0	0	0	.44	1	0
1966	51,500	0	0	0	0	0	.59	1	0
1967	68,200	0	0	0	0	0	.48	0	0
1968	59,300	0	0	0	0	0	.55	0	0
1969	51,600	0	0	0	0	0	.65	1	0
1970	45,500	0	0	0	0	0	.75	1	0
1971	33,670[b]	.26[c]	0	0	0	0	.54	0	1
1972	0	1	0	0	0	0	.47	0	1
1973	0	1	0	0	0	0	.21	0	1
1974	0	1	0	0	0	0	0	0	0
1975	0	1	0	0	0	0	0	0	0
1976	0	1	0	0	0	0	0	0	0
1977	0	1	0	0	0	0	.49[f]	0	1[f]

[a] Allotment rescinded after winter wheat planted. Value represents 1950 allotment total.
[b] Proportion of winter wheat to all wheat plantings (74%) multiplied by the 1970 allotment total.
[c] Proportion of spring wheat to all wheat plantings.
[d] Diversion (1962–66, 1969–70).
[e] Set-aside (1971–73, 1977).
[f] The 1977 diversion program and payment per bushel was treated like the earlier set-aside and certificate payment.

the same as the set-aside program in the earlier period.

Attempts to model farm programs after 1977 were an unequivocal failure. The authors suspect that the rapid increase in total crop acreage from 1979 to 1981 was largely in response to anticipated government programs or those already in effect. The new programs let farmers reestablish acreage bases instead of locking them in at historic allotments. Opportunities were abundant to rachet normal crop acreage (NCA) upward by staying out of the program for a year and planting large acreages. There would appear to have been strong convictions among farmers that the government would eventually be imposing strong measures to control production, and, based on past experiences, a large NCA would provide an opportunity to collect lucrative government subsidies.

With the many changes which have been taking place in the programs and the complex interrelationships of the policy and economic variables (see Evans), combined with sophisticated strategies used by farmers, the modeling task might be infeasible except for individual year dummy variables to remove these years from the sample. Since these years are on the end of the sample, that would be equivalent to truncating the sample as was done in

Table 2. Wheat Acreage Response Equations (1949-77)

Equation No.:	United States			Great Plains			
	1	2	3	4	5	6	7
Intercept	−33,546	−19,954	−24,718	−34,613	−33,609	−31,232	−31,575
	(6,826)	(7,221)	(4,417)	(3,192)	(1,904)	(2,779)	(1,375)
Diversion	−4,695	−9,116	−8,539	−3,221	−3,334	−4,065	−4,006
	(979)	(1,387)	(769)	(589)	(385)	(812)	(642)
Set-aside	−4,287	−7,225	−7,026				
	(1,463)	(1,263)	(755)				
No-allotment	25,469	17,190	17,202	12,807	11,577	9,639	9,500
	(4,724)	(4,975)	(2,893)	(3,086)	(2,595)	(3,066)	(2,274)
Mkt. quota	63,822			55,424	54,743		
	(7,057)			(3,956)	(3,179)		
Allotment	.326	.190	.184	.168	.151	.130	.127
	(.074)	(.077)	(.044)	(.049)	(.042)	(.048)	(.035)
Sept. $Price_{t-1}$	15,390	13,564	14,191	12,797	12,809	13,187	13,548
	(2,571)	(2,149)	(1,791)	(1,596)	(1,685)	(1,374)	(1,291)
$Price_{t-2}$	8,302	9,206	11,005	6,825	7,227	5,134	5,134
	(3,365)	(2,853)	(2,262)	(2,186)	(2,467)	(2,017)	(1,837)
$Price_{t-3}$	17,661	21,385	21,533	12,104	11,721	12,334	12,699
	(3,819)	(3,104)	(3,032)	(2,416)	(2,567)	(2,188)	(2,007)
$Price_{t-4}$	7,486	8,547	9,337	10,284	9,965	8,635	8,413
	(2,944)	(2,632)	(1,844)	(1,980)	(1,839)	(1,892)	(1,373)
Geometric lag	.150			.247	.260	.322	.317
	(.049)			(.038)	(.024)	(.052)	(.032)
MA(1)					.830		.860
					(.235)		(.244)
AR(1)			−.600				
			(.151)				
Adjusted R^2	.984	.987	.983	.986	.984	.990	.988
Std. error est.	1,370	1,212	766	908	693	748	471
Degrees freedom	15	9	7	16	15	9	8
Long-run price elasticity	.92	.84	.90	1.26	1.27	1.31	1.31

Notes: Prices are in natural logarithms and "$Price_i$" is the season average for crop year i, where i denotes calendar year of harvest. Equations containing the marketing quota dummy variable have the prices set equal to zero during the quota years (1954–63). These same equations (1, 4, and 5) contain dummy variables for years 1950 and 1956–57. The remaining equations (2, 3, 6, and 7) contain dummy variables for the quota years 1954–63 and for 1950. Adjusted R-squared is the square of the sample correlation between the dependent variable and a predicted value which excludes the information content of the estimated AR or MA disturbance structure. Standard errors of regression coefficients are in parentheses. Wheat acreage is in units of 1,000. The 1949–77 sample average acreages are 62,627 and 44,401 for the United States and Great Plains, respectively.

this study. One of the models described above treats the period of marketing quotas (1954–63) this same way.

Statistical Results

Acreage response equations are given in table 2 for the United States and Great Plains. Eight states comprise the Great Plains: Montana, North Dakota, South Dakota, Colorado, Nebraska, Kansas, Oklahoma, and Texas. Two different price indices for alternative crops which might affect planted wheat acreage were tested in various regression equations. Neither the price index for feed grains nor the com-

posite of feed grains and hay showed much significance in any of the equations. Typically the *t*-ratio was less the 1.0 in absolute value, and the regression coefficient was positive. The equations in table 2 exclude any price for alternate crops.

Numbers in parentheses are asymptotic standard errors; see the first footnote in table 2 for an explanation of the R-squared measure as well as the notation for prices. Note that the prices are in natural logarithms, but acres are not logged. Reported elasticities are for mean acreages during the sample period, 1949–77.

The quota models in table 2 are identified by the presence of the marketing quota variable, and the other equations are the dummy

Table 3. Individual State Regression Equations, 1949-77

State	Sept. Price $t-1$	Season Price $t-2$	Season Price $t-3$	Season Price $t-4$	Geometric Lag Parameter	Standard Error Estimate	$\bar{R}^2$	Long-Run Elasticity	Average Acreage
N. Dakota[a]	3,519 (554)	396 (708)	2,877 (865)	365 (553)	.379 (.061)	347	.964	1.40	8,230
Montana	2,165 (621)	826 (602)	569 (679)	2,284 (430)	.573 (.080)	224	.916	2.85	4,780
S. Dakota	1,500 (304)	-116 (291)	1,659 (286)	1,025 (237)	.238 (.068)	112	.976	1.90	2,802
Nebraska	807 (287)	952 (414)	641 (465)	1,063 (362)	.462 (.071)	137	.945	1.86	3,451
Colorado	786 (450)	-265 (593)	920 (658)	427 (467)	.583 (.088)	209	.783	1.50	2,983
Kansas	2,158 (679)	3,103 (903)	2,556 (991)	3,826 (855)	.121 (.066)	399	.957	1.13	11,675
Oklahoma[b]	991 (476)	753 (568)	1,721 (548)	1,133 (630)	.222 (.105)	266	.939	1.03	5,729
Texas[b]	1,238 (648)	1,239 (933)	968 (858)	826 (970)	.305 (.140)	312	.910	1.29	4,751

Note: Prices are in natural logarithms and several agricultural program and dummy variables were in the equations (see text for details).
Degrees of freedom are equal to fifteen, and standard errors of coefficients are in parentheses.
[a] September price is replaced by March price in year t. A large outlier in the residuals for 1971 is dummied out because only spring wheat producers had time to respond to a late policy announcement.
[b] Estimated in first differences, but the $\bar{R}^2$ is with respect to levels for comparison with other states.

model with individual year dummies for 1954–63. Coefficients on the individual year dummies are not given in table 2 to save space.

The disturbance structure was explored by performing an ARMA analysis on the residuals from the equation specified with the classic properties for the disturbance. The first-order moving-average, MA(1), disturbance was estimated by a two-step procedure where the parameter estimate from the residual analysis was taken as the estimate; the reasons for this method are given in (Burt). The standard errors in the MA(1) parameter estimates were calculated indirectly from a likelihood ratio t-statistic. The autoregressive AR(1), parameter for the third equation was also estimated by the two-step procedure because the estimate was implausibly large in absolute value by Cochrane-Orcutt iteration. The small number of degrees of freedom in this equation might be the main problem.

In both the United States and Great Plains equations, results are given for both the classic and AR(1) or MA(1) disturbances, except for the quota model for the United States where the classic properties appeared adequate. Equations (1) and (2) for the United States provide a direct comparison of the quota and dummy models. Note that the geometric lag

in the first equation is significant but very small in its effect, while lack of significance led to its deletion in the second and third equations. All three of the U.S. equations yield point estimates of respective parameters which are quite close to one another considering the number of degrees of freedom involved. The price variables in particular have coefficients which change little from one model to the other, and the long-run price elasticities are nearly equal.

The four equations for the Great Plains [equations (4)–(7)] show even less variation across different specifications. The disturbance structure and geometric lag parameter estimates are nearly the same for the quota and dummy models. Likewise, the long-run price elasticities are nearly equal.

Separate individual state equations were estimated for the Great Plains to test for possible spurious statistical results caused by aggregation. Summary results from these equations are reported in table 3 for the quota model [comparable to equations (4) and (5) in table 2]. In general, the statistical precision is much less than for the aggregate, but the same structure appears to hold across each of the individual states. In particular, the long-run elasticities are all greater than unity and their acreage weighted average is 1.50, which is quite

close to the estimates in table 2 of about 1.30. Results for the dummy model (not reported) gave a weighted average elasticity of 1.57, which is also close for this type of comparison.

There were obvious specification problems for Oklahoma and Texas which required estimation in first differences to get a stable structure on the disturbance term; possibly omission of cotton price for these states is part of the problem. Nevertheless, point estimates of the price coefficients are consistent with the aggregate equations. The lagged price structure for Kansas mimics that for the Great Plains very closely and with good statistical precision. North Dakota was estimated using March price in place of September price because most of the acreage is in spring wheat. All states except Oklahoma and Texas tended to have negative autocorrelation in the residuals, but the results in table 3 are for a classic disturbance specification.

Both Montana and South Dakota contain substantial acreages of spring wheat, which suggests that March price is a relevant variable in these states as well as September price. Separate equations for spring and winter wheat were estimated for these two states, but the results were not as plausible as an aggregate model using September price. Disaggregated models in dryland farming introduce more random variation in plantings which are associated with localized weather conditions.

An analysis of the region east of the Great Plains (not reported here) suggested a change in structure between 1949–54 which appeared as a gradual increase in acreage response to price. It is possible that development of the practice of double cropping wheat with soybeans in the Southeast was responsible for this change in structure. This result prompted reestimation of the U.S. acreage equation for the period 1954–77. Results from the quota model [counterpart of equation (1) in table 2] are,

$$(3) \; \hat{A}_t = -73,008 - 4,084X_1 + 83X_2 + 25,768X_3$$
$$\quad\quad (15,431) \quad (895) \; (2,057) \quad\quad (4,600)$$
$$\quad + 99,906X_4 + .355X_5 + 21,499SP_{t-1}$$
$$\quad\quad (14,495) \quad (.075) \quad\quad (3,243)$$
$$\quad + 14,920Price_{t-2} + 19,684Price_{t-3}$$
$$\quad\quad (3,980) \quad\quad\quad (3,596)$$
$$\quad + 18,531Price_{t-4} + .176\hat{A}_{t-1},$$
$$\quad\quad (4,778) \quad\quad\quad (.049)$$

where $X_1, \ldots, X_5$ are the first five ordered vari-

ables in table 2, and the price variables are as defined earlier. The Durbin-Watson statistic is 2.58, which implies some negative autocorrelation in the sample residuals; but estimation with an AR(1) disturbance gave essentially the same point estimates and precision.

The degrees of freedom in (3) are 13; the adjusted R-squared is .979, and the *SEE* is 1,223. Precision on the price parameter estimates in (3) is not as good as equation (1) in table 2, but the point estimates are larger in (3). Long-run elasticities at the acreage sample means in 1954–77 and 1949–77 are 1.53 and 1.45, respectively, much larger than reported in table 2 for the United States. The long-run elasticity estimate given in (Burt, Koo, and Dudley) for the period 1961–76 was 1.44, very close to the above results for 1954–77.

Distributed lag patterns are given in table 4 for the United States and Great Plains. The lag coefficients are normalized relative to long-run response. The response measured in acres (thousands) can be obtained by multiplication of the coefficients by the last row of table 4. These acreage responses are equal to $\partial A_{t+j}/\partial(\log P_t)$, i.e., the net change in acreage j years after the once-and-for-all increment to the logarithm of wheat price. The partial derivative with respect to price, instead of its logarithm, is inversely proportional to the level of price; but for a given price, the relative weights in table 4 would be unchanged. The U.S. equation for 1949–77 (first equation in table 4) gives a noticeably different distributed lag in comparison with the 1954–77 sample (last column, table 4). The distributed lags of the Great Plains (1949–77 sample) and the United States for 1954–77 are nearly identical.

Tests of Specifications

Special Wheat Payments

As explained earlier, the per bushel certificate payments in 1963–73 and the deficiency payment in 1977 were added to wheat prices. To test whether these payments were, in effect, like an addition to prices received by farmers, an equation was estimated for the Great Plains with the certificate payment as an additional independent variable and lagged the same as prices which include the payment. This provides a nested hypothesis framework for which

the *F*-statistic was 1.05, with four and five degrees of freedom, which is marginally significant at about the 40% level. These results were for the dummy model, equation (6) in table 2.

A similar test was performed using the quota model, equation (4) in table 2, but it was not exactly nested. The object was to remove the payments from prices and get a separate estimate for net effects of the payments for direct comparison to those for prices. Therefore, certificate payments were not added to prices and the payments were entered as before; but prices were in logarithms, which makes the test only approximate. Point estimates of the coefficients on the payment variables were 6,434, −349, 4,478, and 4,330 with standard errors of about 2,000. These are for payments in the crop years $t - 1$ to $t - 4$. Only the coefficient for $t - 2$ is a violation of the general pattern of the coefficients on prices, and this anomaly was traced to the influence of one data point. The *F*-statistic calculated as if the hypothesis were nested was .35, with five and twelve degrees of freedom. In summary, there is little reason to question the addition of certificate payments to prices to represent the effect of the certificate and deficiency payment programs.

Futures Prices

The use of wheat futures price in place of September price at planting time for winter wheat was tested by replacing September with the futures price. The Great Plains was used once again, for this comparison because results for this region seemed to be the most reliable. The quota model was used, equation (4) in table 2. With the futures price, the standard error of the estimate (*SEE*) increased from 908 to 1,277, and the adjusted *R*-squared fell from .986 to .972.

These results are consistent with the forecasting performance of both price variables. Season average price is defined on a marketing year (not production) so that year *t* is July of calendar year *t* through June of calendar year $t + 1$. Therefore, in the notation used earlier, $Price_t$ can be forecast by either SP_{t-1} (September price the fall the wheat is planted) or by F_t, which denotes the futures price defined earlier (fall settle close prices for July contracts). Note that P_{t-1} is not observable in the fall

Table 4. Distributed Lag Response to the Logarithm of Price

Source:	Table 1		Text
Equation No.:	1	5	3
Order of Lag	(U.S.)	(G.P.)	(U.S.)
0	.268	.227	.237
1	.185	.187	.207
2	.335	.257	.254
3	.181	.243	.249
4	.027	.063	.044
5	.004	.016	.008
6	.001	.004	.001
7	0	.001	0
8	0	0	0
Average lag	1.53	1.80	1.69
Long-run response	57,458	56,381	90,575

Note: The coefficients are acreage response relative to the long-run response.

since only about two months of the marketing year $t - 1$ have been experienced. Nevertheless, the forecast equations were specified with an AR(1) disturbance to get more efficiency in estimation and more reliable standard errors on parameter estimates. The fitted equations over the sample period 1949–77 are

$$(4) \quad \hat{P}_t = 1.55 + 2.23D_{73} + .497SP_{t-1} + .789\hat{u}_{t-1}$$
$$\qquad (.52) \quad (.33) \qquad (.106) \qquad\quad (.116)$$
$$\qquad \bar{R}^2 = .673, \qquad SEE = .386,$$

$$(5) \quad \hat{P}_t = 1.92 + 1.92D_{73} + .394F_t + .767\hat{u}_{t-1}$$
$$\qquad (.75) \quad (.41) \qquad (.169) \quad (.121)$$
$$\qquad \bar{R}^2 = .623, \qquad SEE = .486,$$

where $\hat{u}_{t-1}$ is the calculated lagged disturbance, D_{73} is a dummy variable for 1973 which was a large outlier, and $\bar{R}^2$ excludes the contribution of $\hat{u}_{t-1}$. The $\bar{R}^2$, *SEE*, and relative *t*-ratios for SP_{t-1} and F_t all suggest that September price received by farmers is superior to the futures price in forecasting season average price received by wheat farmers for their crop.

The relatively poor performance of the futures price in the acreage equations could be from the greater forecasting information contained in the September price and/or from the source of information chosen by farmers. If farmers focus most of their attention on fall prices quoted in their local areas, the futures price is largely irrelevant except insofar as it shapes spot prices at local markets, and temporal variation in the basis could be a problem.

Recursive Residual Analysis

Equations for the United States and Great Plains were tested for specification problems using sequential post sample conditional predictions. The quota model was used because it preserves more degrees of freedom.

Equation (1) in table 2 was used for analysis of the U.S. model. The 1949–77 sample was sequentially reduced by dropping the latest year until the 1949–72 sample; then a degree of feedom problem and lack of precision encouraged extending the sample back to 1945 although these early years did not appear to show a completely consistent response with the 1949–77 period. The last sample used was 1945–66, which provided a total of eleven observations for one-year-ahead prediction. The root mean square error is 3,200 (thousands of acres) and the bias is 519. The former is quite consistent with the theoretically calculated standard errors of prediction over the sample, and the bias is clearly within common statistical variation. A formal statistical test on the entire set of standardized residuals (see Harvey, p. 156) gave a *t*-statistic equal to .17 with 10 degrees of freedom. The two- and three-year ahead prediction root mean square errors are 3,309 and 2,894, respectively, with biases −85 and −355. In fact, the post-sample prediction performance is good out to seven years. However, 1977 is always predicted with a residual larger in absolute value than twice its standard error.

The same procedure was used on the Great Plains model using equation (4) in table 2. The results are more favorable than for the United States in that the largest ratio of a residual to its standard error was 1.89 in absolute value. This includes all predictions out to seven years. The summary measures of root mean square error and bias were also most encouraging for this specification.

Summary and Conclusions

The dynamic structure of wheat acreage supply response is considerably more complex than previous studies have recognized. The distributed lag response is quite protracted and is not well approximated by the commonly applied geometric lag. It is conjectured that this unusual lag structure emanates from latent state variables in the production process with crop rotations playing an important role. It is be-

lieved that the practice of summer fallow in the Great Plains tends to give this choppy lagged response.

Long-run wheat supply response is quite elastic for the aggregate United States, around 1.5 for the period 1954–77 and .90 using 1949–77 as the sample. This much divergence with the choice of samples suggests some aggregation problems in the U.S. equation. In the Great Plains the elasticity is about 1.3; results for this region were very robust to alternative specifications and sample periods. These elasticities are considerably larger than previous studies have found but quite compatible with estimates for other major wheat producing nations like Canada, Australia, and Argentina (see Schmitz and Bawden, p. 25).

For the United States, the proportion of long-run response experienced after a finite number of periods is .24, .44, .70, .95, and .99 over the first through fifth consecutive years, respectively. These proportions for intermediate-run responses are nearly the same for the Great Plains.

The functional form used for acreage response to price was semilog with prices in logarithms. As a consequence, price elasticity is inversely proportional to the associated acreage level. The larger long-run elasticity reported above for the United States is 1.5 at the mean acreage (1954–77) but at the lowest and highest acreages in the sample, the elasticities are 1.9 and 1.1, respectively.

The authors' lack of success in introducing post-1977 data into the sample to give a comprehensive model for the entire period after 1949 may be viewed by some as casting serious doubt on the results reported here. At the close of this research effort, data through 1983 were being used, which is only six additional years into the nation's new experiment in farm policy. Possibly a better perspective can be obtained as we reflect back on a longer period of experience with these new programs. Just as the marketing quota years (1954–63) have largely defied integration into a comprehensive acreage response equation, so may a period in the late 1970s and early 1980s.

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Appendix

Data Sources

Annual state wheat price data through 1972 were obtained from *Agricultural Statistics,* and later price data were taken from annual summaries of *Agricultural Prices.* Feed grain, feed grain and hay, and prices paid for production items indices were collected from the 1980 annual summary of *Agricultural Prices.* September state wheat prices were taken from September issues (1943–58) and annual summaries (1959–77) of *Agricultural Prices;* likewise, for March prices in North Dakota. State seeded acreage data were taken from *Agricultural Statistics* and annual summaries of *Crop Production.* All of these sources are published by the U.S. Department of Agriculture.

Elaboration of Policy Variables

Although the allotment for 1951 was eventually rescinded, this was not done until well after the winter crop had been planted. Therefore, 1951 was treated as an allotment year, and the 1950 allotment was used. In 1971 the allotment program was modified so that it no longer restricted total plantings. However, this was not announced until after winter wheat had been seeded. Following Garst and Miller, a special allotment total was calculated as the proportion of winter wheat to all wheat plantings (74%) multiplied by the 1970 allotment which represented the allotment level for winter wheat program participants. The no-allotment dummy variable in table 1 was then modified to reflect the needed change in the intercept, i.e., the normal value of zero for an allotment year was replaced by the fraction spring wheat comprised of total wheat acres (.26). This intercept shift variable is assigned a value of one during no-allotment years.

The no-allotment dummy variable was partitioned into two separate variables to test whether the nearly twenty years of controls had changed the structure of acreage responses starting in 1972 after the allotment variable was no longer relevant. There was little statistical evidence of any change in structure.

The assumption of zero response to prices during the quota years was tested statistically by introducing variables defined as the product of the quota dummy and the lagged prices, but these interaction variables were very weak statistically and insignificant as a group. Another such interaction variable defined as the product of the quota dummy and the acreage allotment was tested, but it was also insignificant.

Because the period of the Soil Bank program (1956–58) occurred within that for the marketing quota, the dummy model with separate year dummies accounted for this special program. For the quota model, 1956 and 1957 individual year dummies were used and none was needed for 1958 based on the statistical results. The lack of significance for 1958 might have been expected because the acreage reserve program rules were much more restrictive compared to 1956–57. In particular, summer fallow land no longer qualified for the reserve and farmers had to reduce their total harvested crop acreage by the number of acres put in reserve, thus discouraging farmers from participation in the program.

The marketing certificate payment is the sum of the domestic and export payments to program participants.