The Constancy of the U.S. Wheat Acreage Supply Elasticity

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SUMMARY

This study examines the constancy of the wheat acreage supply elasticity between 1950 and 1976. A binary variable approach is used to test constancy over time and over price levels. The results indicate that this elasticity has not been constant, and the paper suggests a model formulation that is more appropriate than the one used in past research.

AUTHORS

Debra K. Moe is a graduate research assistant and James K. Whittaker and Ronald A. Oliveira are assistant professors in the Department of Agricultural and Resource Economics, Oregon State University, Corvallis.

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THE CONSTANCY OF THE U.S. WHEAT ACREAGE SUPPLY ELASTICITY

Debra K. Moe, James K. Whittaker and Ronald A. Oliveira

In a recent paper, Houck *et al.* estimated acreage response functions for each of the seven major crops produced in the United States. They included parameter estimates for wheat acreage response, using time-series observations from 1950 to 1970. An attempt to update this analysis by including additional observations from 1971 to 1976 resulted in a large decrease in the elasticity of wheat acreage response with respect to the market price of wheat lagged one year. This decrease can be attributed in major part to changes in the market price coefficient estimates rather than to changes in the ratio of the mean market price over the mean of the acreage data. The parameter instability when updating the analysis of Houck *et al.* makes their results of questionable value for either forecasting purposes or policy analysis.

The purpose of this paper is to analyze two alternative hypotheses for the decrease in the acreage elasticity when six recent observations were added to the data set. The first alternative is that the acreage response function is less elastic at high market prices than at low market prices. Since recent observations contain very high market prices, this hypothesis could explain the decline in the elasticity when recent observations were added to the data set. The hypothesis that the acreage elasticity is inversely related to the market price also is consistent with economic theory. When the wheat price is low, a small price increase likely will elicit a relatively large shift in resource use to wheat production because some resources are well adapted to wheat. As the price of wheat continues to rise, and the shifting resources are less adaptable to wheat production, it will take larger price increases to elicit the same acreage response as was obtained when the wheat price was low. The limiting case occurs when all resources are employed in wheat production and further price increases will elicit no acreage response; hence, at this point, the acreage response elasticity is zero.

The other hypothesis for the decline in the wheat acreage supply elasticity is time oriented. It is possible that because of a change in the market structure, government programs, or price expectations, the wheat acreage supply elasticity dropped in 1971 and remained at the new lower level. Unfortunately, since there is a very close relationship between time and the wheat price, it is not possible to fully separate these two potential influences on the wheat acreage supply elasticity. This paper does, however, shed some light on the constancy of the parameter and elasticity estimates, possible causes of changes in the elasticity, and a methodology for analyzing these changes in an econometric framework.

The remainder of this paper is divided into three major sections. First, the wheat acreage response model used by Houck *et al.* is discussed. A discussion of the empirical parameter estimates and acreage predictions of various model alternatives follows, and the paper ends with a brief summary and conclusion section.

The Model

The linear wheat acreage response model used by Houck *et al.* is

$$AWP_t = f(PMW_{t-1}, PSW_t, DPW_t, RNC_t), \qquad (1)$$

where

AWP_t = wheat acreage planted in year t in 1,000's of acres,

PMW_{t-1} = market price of wheat lagged one year in dollars per bushel,

PSW_t = price support rate for wheat weighted by the percent of wheat acreage eligible for this payment in year t in dollars per bushel,

DPW_t = voluntary wheat diversion payment rate weighted by the percent of wheat acreage eligible for this payment in year t in dollars per bushel [1/],

RNC_t = index of Southern Plains range conditions in year t.[2/]

The market price of wheat lagged one year is included as a measure of farmers' price expectations for the coming year. The estimated coefficient on this variable is assumed to be positive, i.e., increases in the lagged wheat price will elicit corresponding increases in planted wheat acreage. The weighted support price for wheat acts as a guaranteed income or price for the eligible acreage, and, therefore, its estimated coefficient also should be positive. Wheat diversion may be treated conceptually in the same manner as all production alternatives to wheat, i.e., a producer may use his land for wheat production or wheat diversion. Therefore, an increase in the weighted wheat diversion price should cause planted wheat acreage to decline. The index of range conditions in the Southern Plains Region is a proxy variable for weather conditions at the time wheat is planted. An increase in this index indicates more favorable weather conditions and hence an increase in acreage planted to wheat.

Noticeably absent from this model are the prices of other products that are production alternatives for wheat. This omission follows from the argument of Lidman and Bawden that there really are no economic substitutes for wheat, given the historical relationships among crop prices. If weather is favorable in the fall, wheat is planted. If not, a substitute crop is planted the following spring or the land is summer-fallowed during the next crop year. In a regional analysis, Hoffman included no substitute crop prices except for cotton in the Southern Plains Region, but the coefficient on that price was not statistically significant. This research will follow the precedent of the above papers, and omit the prices of production substitutes.

Empirical Results

Houck et al. (1950-1970)

Applying ordinary least squares (OLS) to observations from 1950 to 1970, model (1) was estimated as follows:

$$AWP = -34.89 + \underset{(2.97)}{13.45}\ PMW + \underset{(2.69)}{22.59}\ PSW - \underset{(3.15)}{3.78}\ DPW + \underset{(0.18)}{0.48}\ RNC, \qquad (2)$$

where the numbers in parentheses are the standard errors of the estimated coefficients.[3/] All the estimated coefficients have the anticipated signs and all except that on the weighted diversion price are statistically significant at five percent. The model provides a relatively good fit of the data as indicated by the R^2 of .89. The estimated acreage response elasticity with respect to the market price of wheat is 0.39 (when estimated at mean levels of wheat acreage and wheat price). This elasticity estimate is very similar to earlier estimates of Nerlove in the range 0.34 to 0.48.

Houck et al. (1950-1976)

The parameters of model (1) were re-estimated with six additional observations (1971 to 1976) added to the data set to obtain

$$AWP = 1.29 + \underset{(1.33)}{4.21}\ PMW + \underset{(3.26)}{21.42}\ PSW - \underset{(4.00)}{2.28}\ DPW + \underset{(0.21)}{0.23}\ RNC. \qquad (3)$$

Again, all signs are as anticipated. In equation (3) the estimated coefficients for range conditions and weighted diversion price are not significant. The R^2 for this equation is .82. Since the coefficients in equation (3) are all considerably smaller than those of equation (2), the null hypothesis that the vectors of coefficients in these two equations are equal was tested.[4/] This hypothesis was rejected (at the five percent level of probability), indicating that the parameters estimated by Houck *et al.* may no longer be useful, and shedding some doubt on the accuracy of those parameters estimated in equation (3). The acreage elasticity with respect to wheat price decreased to .13 even though the ratio of mean price to mean acreage increased slightly. This large decrease in the parameter estimate (estimated at the means of market price and acreage) for lagged market price and, subsequently, the elasticity also makes the model of equation (1) somewhat questionable for current analysis. The derivation of the elasticities is summarized in Table 1.

TABLE 1. Summary of the estimation of the elasticities for the model formulated by Houck et al. for 1950-1970 and 1950-1976

Model	Coefficient on PMW	$\frac{\bar{P}}{\bar{Q}}$	Elasticity
1950-1970	13.45 (2.97)	0.029	0.39
1950-1976	4.21 (1.33)	0.032	0.13

(Standard errors are in parentheses)

Constancy Over Price

The coefficients in equations (2) and (3) were estimated under the implicit assumption that the wheat acreage elasticity with respect to the wheat market price is constant for all observations. If this assumption is not true, the coefficients presented above are biased.

One possible explanation for the decrease in the elasticity and the lagged market price parameter when comparing the model for 1950-1970 with the model with recent observations added is that the acreage elasticity is not constant over the entire range of the historical wheat price series. To test this hypothesis, separate intercept and wheat price slope variables for low and high prices were incorporated in the model. "Low" prices were somewhat arbitrarily determined to be those below \$1.80 per bushel.[5/] Two intercept shifter variables were substituted for the constant term in equations (2) and (3). One, C_{lo}, corresponds to the constant when the market price is low (C_{lo}= 1 if PMW $\leq$ 1.80 and = zero otherwise). The other, C_h, corresponds to high market prices for wheat (C_h = 1 if PMW > 1.80 and = zero otherwise). In addition, two slope shifter variables were created by multiplying C_{lo} by PMW (PMW_{lo}) and C_h by PMW (PMW_h). The coefficients on PMW_{lo} and PMW_h correspond to the inverse of the slope of the acreage response function when the market price of wheat is below or above \$1.80 per bushel respectively. The result is a segmented linear acreage supply curve (Figure 1), where the "b" with a variable name for a subscript indicates the estimated coefficient for that variable. The estimated acreage supply curve corresponds to the two solid portions of the linear relationships.[6/]

The parameters of the model in equation (1) were re-estimated including the two constants and the two price variables using the sets of observations from 1950 to 1970 and from 1950 to 1976. The estimated coefficients and standard errors (in parentheses) are presented in Table 2. All the estimated

TABLE 2. Empirical results for model allowing slope and intercept shifts related to wheat market price

	Independent Variable							
Model	C_{lo}	C_h	PMW_{lo}	PMW_h	PSW	DPW	RNC	R^2
1950-1970	-50.43 (17.11)	13.85 (29.96)	25.01 (5.59)	-11.25 (12.48)	28.04 (3.08)	-1.90 (3.04)	0.36 (0.16)	.93
1950-1976	-49.41 (15.13)	-9.65 (11.97)	23.47 (4.52)	0.50 (1.13)	25.29 (2.36)	-2.16 (2.83)	0.42 (0.14)	.93

coefficients in both equations have the anticipated signs except in the case of

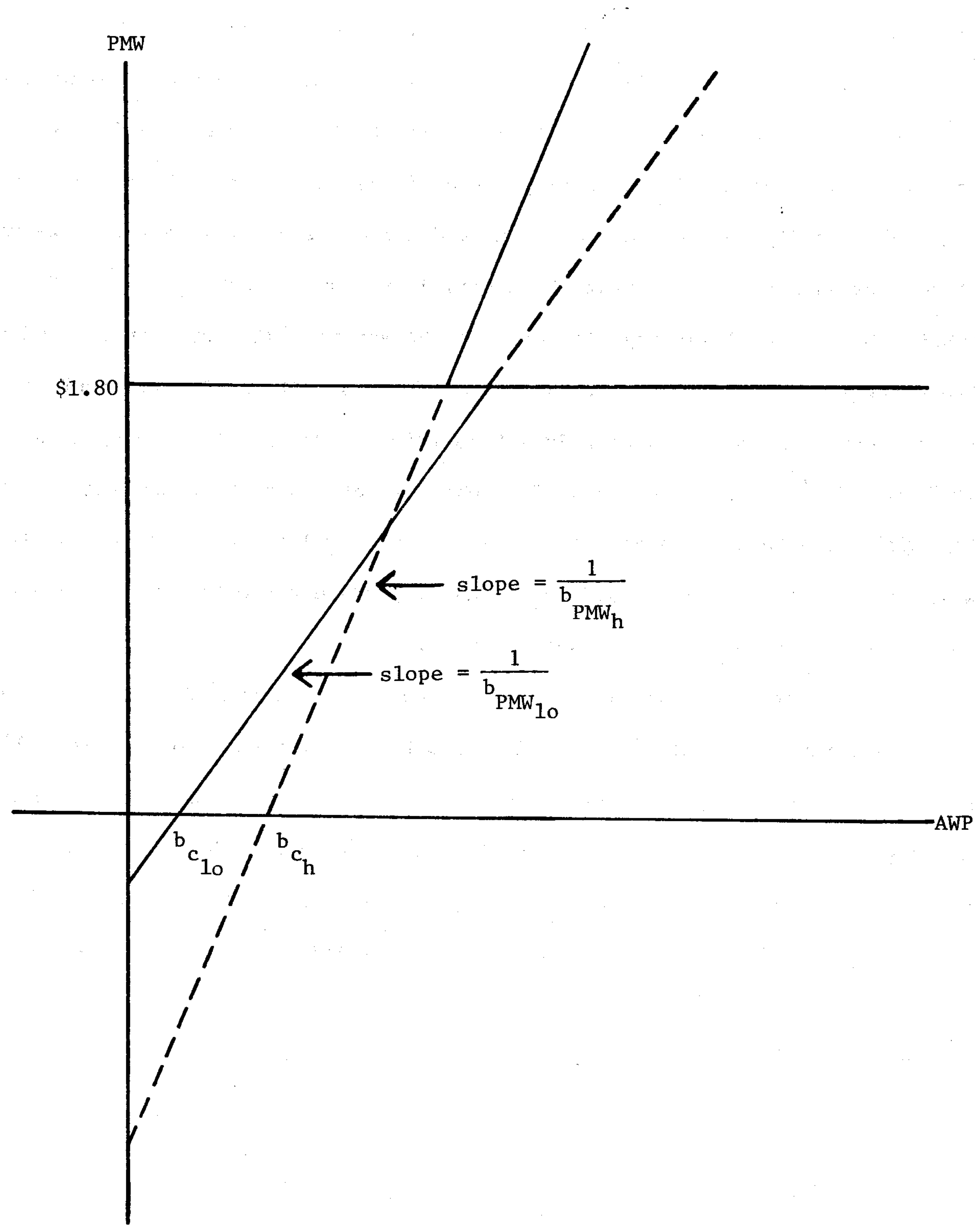

FIGURE 1. The segmented linear supply function

high wheat price in the equation estimated with observations from 1950 to 1970. The coefficients for the high constant and high market price are nonsignificant in both equations. This apparent lack of significance of these coefficients is likely a result of multicollinearity, as evidenced by the high R^2's and very high collinearity between each constant and its corresponding market price variable. The null hypothesis that the coefficients for C_{lo} and C_h, i.e., the two constants, are equal was rejected at five percent for both equations. Similarly, the two wheat price slope coefficients also were significantly different both for the equation estimated with data from 1950 to 1970 and that using data from 1950 to 1976.[7/] All estimated coefficients except those corresponding to the high price constant and slope variables are very similar in these two models, which is not the case in equations (1) and (2) where there is only one constant and market price variable for each equation.

The estimated low and high price acreage supply elasticities are .66 and -.36 respectively for the model estimated with observations from 1950 to 1970.[8/] However, as previously mentioned, the high price elasticity was derived from a non-significant coefficient. For the 1950 to 1976 model, the low and high price elasticities are .62 and .02 respectively. Estimation of these elasticities is summarized in Table 3. The decrease in the elasticity is again attributable

TABLE 3. Summary of the estimation of the elasticities for the model segmenting low and high market prices for the years 1950-1970 and 1950-1976

Model	Coeff. on PMW_{lo}	Coeff. on PMW_h	$\bar{P}/\bar{Q}$ (low price)	$\bar{P}/\bar{Q}$ (high price)	Elasticity (low price)	Elasticity (high price)
1950-1970	25.01 (5.59)	-11.25 (12.48)	0.026	0.032	0.66	-0.36
1950-1976	23.47 (4.52)	0.50 (1.13)	0.026	0.036	0.62	0.02

(Standard errors in parentheses)

predominantly to a decrease in the parameter estimate on lagged market price (especially for observations with high prices) rather than a change in the ratio of mean price over mean acreage. For both models, the low price elasticities are considerably larger and the high price elasticities are considerably smaller than earlier estimates by Nerlove and by Houck et al. The empirical results support the hypothesis stated earlier that the wheat acreage supply elasticity is inversely related to the market price of wheat for both data sets.

Constancy Over Time

Another possible explanation for the instability of the estimated coefficients for equation (1) is the possibility of a temporal shift in the acreage response function for wheat. To test this possibility, a model formulation similar to that of the previous section was used. The constant term in equation (3) was replaced with two constants. One constant, C_e, corresponding to "early" observations ($C_e = 1$ if the observation is pre-1971 and zero otherwise). The other constant, C_{la}, corresponds to "late" observations ($C_{la} = 1$ if the observation is post-1970 and zero otherwise). In addition, early and late wheat price variables were formed by multiplying C_e and C_{la} by PMW. These variables are PMW_e and PMW_{la}, respectively, and they replace the PMW variable in equation (1). The results of parameter and standard error estimation of the temporal shift model are presented as equation (4):

$$\begin{aligned} AWP = & -35.03\ C_e - 23.55\ C_{la} + 13.62\ PMW_e + 4.45\ PMW_{la} + 21.78\ PSW \\ & \ \ (17.31) \qquad (15.38) \qquad (2.95) \qquad (1.25) \qquad (2.53) \\ & - 3.52\ DPW + 0.49\ RNC \\ & \ \ (3.12) \qquad (0.18) \end{aligned} \tag{4}$$

All estimated coefficients have the anticipated signs and all except those for the late constant and diversion price are statistically significant at five percent. The R^2 is .90, indicating the model provides a good fit of the data.

The null hypothesis that the two constants are equal could not be rejected at five percent (it could be rejected at ten percent, however). The market wheat price coefficients for early and late years differ significantly. The estimated coefficients for support price, diversion price, and range conditions are nearly identical to those in equation (2). The similarity of these coefficients lends credibility to the hypothesis that no temporal shift occurred in the relationship between these variables and planted wheat acreage.

The estimated elasticity of acreage with respect to the market price of wheat for the early time periods is .40, virtually identical to the estimates of Nerlove and Houck *et al.* The late period elasticity is .18, considerably less than that for the earlier period.

Constancy and the Temporal-Price Interaction

Since the high market prices of wheat tend to coincide with the later observations, a model including the temporal-price interaction for the constant and market price of wheat was formulated to try to separate these two effects, i.e.,

$$AWP = f(C, C_{elo}, C_{eh}, C_{lalo}, PMW, PMW_{elo}, PMW_{eh}, PMW_{lalo}, DPW, PSW, RNC), \quad (5)$$

where C = 1 for all observations,

$C_{elo} = C_e \times C_{lo}$,

.

.

.

$PMW = PMW \times C$,

$PMW_{elo} = PMW \times C_{elo}$,

.

.

.

DPW, PSW, and RNC are as defined earlier.

The variable, C, corresponds to the constant term for those observations that are both late (post-1970) and have a high market price for wheat (greater than

\$1.80 per bushel). The constant C_{elo} is interpreted as the addition to the constant term, C, if the observation has a low market price (less than or equal to \$1.80 per bushel) and is an early observation (pre-1971). The interpretation of the other constant and slope interactions are similar. They indicate the addition to the constant (slope) if the observation falls in the categories defined by the subscripts on the variable name, i.e., C (PMW). Table 4 contains

TABLE 4. Summary of interpretation of constant interaction and slope interaction coefficients

Characteristics of Observation			
Temporal	PMW	Intercept	Slope
late	high	b_c [a/]	b_{PMW}
early	low	$b_c + b_{c_{elo}}$	$b_{PMW} + b_{PMW_{elo}}$
early	high	$b_c + b_{c_{eh}}$	$b_{PMW} + b_{PMW_{eh}}$
late	low	$b_c + b_{c_{1alo}}$	$b_{PMW} + b_{PMW_{1alo}}$

a/ The "b" corresponds to the estimated coefficient.

a summary of the coefficient interpretations for the various constants and market price variables. Using observations from 1950 to 1976, model (5) was estimated as follows:

$$
\begin{aligned}
AWP = {} & -58.12 + \underset{(30.82)}{7.08\, C_{elo}} + \underset{(42.36)}{71.57\, C_{eh}} + \underset{(32.91)}{5.14\, C_{1alo}} + \underset{(7.88)}{12.70\, PMW} \\
& + \underset{(8.90)}{12.38\, PMW_{elo}} - \underset{(15.44)}{23.95\, PMW_{eh}} + \underset{(11.43)}{12.08\, PMW_{1alo}} + \underset{(2.94)}{28.10\, PSW} - \underset{(2.92)}{1.82\, DPW} \\
& + \underset{(0.16)}{0.36\, RNC}
\end{aligned}
\tag{6}
$$

Only the estimated coefficients for range conditions and the weighted price support are significant at five percent. Multicollinearity very likely was the major cause for the non-significance of other coefficients as evidenced by simple correlations exceeding .99 between each constant shift variable and its corresponding slope shift variable. Using .2 as the critical value, the estimated coefficients for the early-high intercept shifter, the slope for late-high observations, and the early-low and early-high slope shifters also are significant. Therefore, some evidence exists that the constant and slope coefficients are not homogeneous across all observations. The R^2 increased to .95.

The estimated acreage supply elasticities with respect to the market price of wheat were almost identical for observations corresponding to the early-low, late-low, and late-high categories (.657, .654, and .649 respectively). Although these elasticities are considerably larger than those of Nerlove and Houck *et al.*, they are similar to that estimated for observations corresponding to low price observations from an earlier model formulation. The acreage supply elasticity for early-high prices was negative (-.356).

Prediction Capabilities of the Models

As a further test of the model formulations presented in this paper, they were compared with respect to their ability to correctly predict acreages over the time periods used for parameter estimation and to correctly predict acreages for 1971 to 1976 when this is an extension of the data set used for model estimation. The average percent prediction errors and the standard deviations of the percent prediction errors are presented in Table 5 for each model previously discussed.

TABLE 5. Prediction Capabilities of the Models

Model [a]	1950 to 1970 Percent Error	1950 to 1970 Standard Deviation	1950 to 1976 Percent Error	1950 to 1976 Standard Deviation	1977 Percent Error
3.1 Houck et al. (1950-1970)	4.47	8.83	7.54	9.47	26.3
3.2 Houck et al. (1950-1976)	5.86	13.49	5.88	13.54	11.0
3.3 Price segmentation (1950–1970)	3.70	6.26	6.47	8.57	6.3
3.4 Price segmentation (1950–1976)	3.80	6.31	3.62	5.51	15.2
3.5 Time segmentation (1960–1976)	4.63	10.34	4.44	9.93	7.4
3.6 Interaction (1950–1976)	4.04	6.70	3.47	6.42	-1.9

[a] The models in equations 3.1 to 3.6 correspond to the models in equations (2), (3), (1.1), (1.2), (4), and (6) respectively.

All shift models reduce the average percent prediction errors and standard deviations of the percent prediction errors considerably as compared to the appropriate model of Houck et al. The model (1950–1976) testing constancy over price [(equation (3.4)] is slightly better at predicting acreage than the model testing constancy over time (3.5). The price-shift models and interaction models also substantially reduce the variation in percent prediction error over the models of equations (3.1) and (3.2). Table 3 tends to support the hypothesis that the model used by Houck et al. is misspecified when estimated using observations from recent years. In addition, based on prediction capabilities, the model allowing for shifts over price are preferable to the temporal shift model. The more complicated interaction model appears to add little to prediction accuracy over the models in equations (3.3) and (3.4).

All six models also were used to forecast the 1977 planted wheat acreage (Table 5). All segmented models out-performed Houck et al.'s original formulation with the exception of the price-shift model estimated with all the observations. The more complicated interaction model forecast considerably more accurately for this year than any of the other formulations.

SUMMARY AND CONCLUSIONS

An attempt to update the well-used wheat acreage response model of Houck et al. resulted in very different parameter estimates. The two hypotheses that the acreage response function for wheat is not homogeneous across all price levels or is not homogeneous over the entire time period from 1950 to 1976 were examined empirically. The results are somewhat mixed. Neither hypothesis provides strong evidence furthering its cause based on statistical properties of the estimated coefficients, but in both cases the vector of estimated coefficients is significantly different from the vector estimated under the assumption of acreage response function homogeneity over all observations. Since the two hypotheses are not independent, an interaction model was used to try to separate the temporal and price discontinuities in the wheat acreage response function, but, again, many coefficients are non-significant and the statistical properties of the estimated equation are poor.

The price shift, temporal shift, and interaction models all clearly outperformed the model of Houck et al. (1950-1976) in terms of acreage prediction capabilities. The price shift model appeared superior to the temporal model in acreage prediction as well.

While the "correct" formulation of the wheat acreage response function is still somewhat uncertain, this research provides considerable evidence to support the hypothesis that the response of wheat acreage to the market price of wheat has not been constant over all observations from 1950 to 1976. Furthermore, considerable care should be exercised in wheat acreage response function parameter estimation, because failure to recognize this fact will result in biased parameter estimates, and, hence, incorrect acreage predictions and policy adjustments.

FOOTNOTES

1/ See Houck et al. (pages 7 to 10 and 31 to 35) for a justification of PSW_t and DPW_t and a description of their quantification under each major policy regime.

2/ Hereafter all time subscripts on the variables will be dropped.

3/ The estimated coefficients of this model differ slightly from those of Houck et al. because of the authors' inability to exactly reproduce their data set.

4/ This test required an alteration of the test presented by Chow. Details of the altered Chow test are given in Fisher and Rea.

5/ This price level was chosen because it roughly corresponds to the mean price and approximately half the observations lie on each side of it.

6/ There is no a priori reason for the high price segment of the acreage response curve to lie to the left of the low price segment at $1.80, but this was determined empirically to be the case.

7/ For a discussion of these hypothesis tests, see Johnston, pp. 155-56.

8/ These elasticities are calculated at the means of the low and high price and corresponding acreage series respectively.

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APPENDIX A

Data for the years 1950 to 1976

	AWP_t	PMW_{t-1}	PSW_t	DPW_t	RNC_t	C_e	C_{la}	C_{lo}	C_h
1950	71.3	1.88	1.74	0	80	1	0	0	1
1951	78.5	2.00	2.02	0	84	1	0	0	1
1952	78.6	2.11	2.20	0	79	1	0	0	1
1953	78.9	2.09	2.21	0	72	1	0	0	1
1954	62.5	2.04	1.77	0	73	1	0	0	1
1955	58.2	2.12	1.45	0	70	1	0	0	1
1956	60.6	1.98	1.40	.84	77	1	0	0	1
1957	49.8	1.97	1.40	.84	63	1	0	0	1
1958	56.0	1.93	1.27	.76	82	1	0	0	1
1959	56.7	1.73	1.27	0	84	1	0	1	0
1960	54.9	1.76	1.24	0	79	1	0	1	0
1961	55.7	1.74	1.25	0	77	1	0	1	0
1962	49.3	1.83	1.18	.25	79	1	0	0	1
1963	53.4	2.04	1.28	.19	81	1	0	0	1
1964	55.7	1.85	1.09	.04	79	1	0	0	1
1965	57.4	1.37	1.53	.09	77	1	0	1	0
1966	54.4	1.35	1.63	.16	82	1	0	1	0
1967	67.8	1.63	1.66	0	80	1	0	1	0
1968	62.5	1.39	1.67	0	82	1	0	1	0
1969	54.3	1.24	1.67	.20	81	1	0	1	0
1970	49.5	1.24	1.48	.18	80	1	0	1	0
1971	53.8	1.33	1.66	0	79	0	1	1	0
1972	54.9	1.34	1.59	.04	80	0	1	1	0
1973	59.0	1.76	1.42	.16	80	0	1	1	0
1974	71.4	3.95	1.85	0	80	0	1	0	1
1975	75.1	4.09	1.83	0	80	0	1	0	1
1976	80.2	3.55	2.28	0	80	0	1	0	1
1977	74.8	2.73	2.42	0	80	0	1	0	1

AWP_t = wheat acreage planted in year t in 1,000's of acres,

PMW_{t-1} = market price of wheat lagged one year in dollars per bushel,

PSW_t = price support rate for wheat weighted by the percent of wheat acreage eligible for this payment in year t in dollars per bushel,

DPW_t = voluntary wheat diversion payment rate weighted by the percent of wheat acreage eligible for this payment in year t in dollars per bushel,

RNC_t = index of Southern Plains range conditions in year t,

C_e = 1 if the observation is pre-1971;

= 0 otherwise,

C_{1a} = 1 if the observation is post-1971;

= 0 otherwise,

C_{1o} = 1 if the $PMW_{t-1} \leq 1.80$;

= 0 otherwise,

C_h = 1 if $PMW_{t-1} > 1.80$;

= 0 otherwise