SUPPLY RESPONSE TO RISK: THE CASE OF U.S. PINTO BEANS

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A standard model of behavior under uncertainty is used to suggest price risk variables for use in a positive supply study. The suggested variables are intuitively appealing and are empirically tested on Pinto bean data. Linearity is assumed and O.L.S. used. The empirical results show that the risk variables greatly improve the statistical fit of the supply equation, are quantitatively important and that a substantial bias occurs if they are neglected. Policy initiatives to reduce Pinto bean price fluctuations need to consider the risk reducing effects on the supply response.

In a recent overview of risk response models, Just [1975, p. 836] contends that the implications of risk for positive response studies have been seriously neglected. He [p. 840] further observes that risk has been shown to be of empirical importance only at relatively disaggregated levels. Clearly, further study is needed of methods and empirical results of the aggregative supply responses to risk. This article demonstrates the empirical importance of price risk in an aggregate U.S. supply equation for Pinto beans. The empirical results show that omission of the risk variables seriously biases the estimates of supply elasticity.

The specifications of the risk variables are derived from a simple model of producer behavior under uncertainty. This model reveals that interaction terms between prices, price variances and covariances of the primary crop and competing crops should be included in the supply equation. The inclusion of these interaction terms contrasts with the traditional approach of specifying risk solely as the standard deviation of crop price. The supply equation is assumed linear in the variables and is estimated with ordinary least squares (O.L.S.). Behrman and Just [1974] both employed more computationally burdensome procedures of nonlinear estimation in their studies of supply response to risk.

Behrman was concerned with the supply response of four major annual crops in small agricultural regions of Thailand. The equation of interest in Behrman's [p. 157] model related desired area planted to expected price, expected yield and to two arbitrarily specified risk variables. The price risk variable was specified as the standard deviation of the crop price over the three preceding production periods relative to the standard deviation of the index of prices for alternative crops over the same period. The yield risk variable was specified as the standard deviation of actual yields of the crop over the three preceding production periods. Three other equations — an adaptive expectations equation for price, a partial adjustment equation for acreage and a trend equation for yields — completed the model.

Just's [1974a] study of crop response in California provides a more general method of evaluating supply response to changing risk. He develops an adaptive risk model which contains expectations on risk variables. The expectations are formed as geometric weightings of the variances and covariances of prices and yields. The procedure is analagous to the

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formation of a price expectations variable as a geometric weighting of past prices. A rigorous justification of the adaptive risk model is presented in Just [1974b], while an intuitive justification is presented in Just [1974a].

Theoretical Risk Model

Assume that the decision maker is an expected utility maximizer and that his expected utility function is quadratic reflecting valuation of the level and variance of expected profits. Let product prices and yields be expressed as random variables with known probability distributions. If production costs were known with certainty, then the expected utility function may be expressed as

$$1)\qquad \max U^* = P'Mx - b/2\, x'Wx$$

where U^* is expected utility; P' is a row vector of expected output prices p_i^* (strictly a price net of unit costs); M is a diagonal matrix of expected enterprise yields with elements m_i; x is a column vector of enterprise levels (acreage); b is a scalar risk coefficient; and W is a covariance matrix of enterprise revenues.

The first order conditions for maximization of the expected utility function give

$$2)\qquad MP - b\,W\,x = 0$$

hence

$$3)\qquad 1/b\, W^{-1}\, M\, P = x$$

The following behaviorial assumptions for all individuals are made.

1. Yields $E[y_i] = m_i$; $\mathrm{Var}\, y_i = \delta_i^2$; $\mathrm{Cov}\,(y_i y_j) = \delta_{ij} \quad i \neq j$

2. Prices $E[p_i] = p_i^*$; $\mathrm{Var}\, p_i = \sigma_i^2$; $\mathrm{Cov}\,(p_i p_j) = \sigma_{ij} \quad i \neq j$

3. $\mathrm{Cov}(p_i y_j) = 0$ for all j.

The zero covariance between prices and yields in assumption 3 implies no relation between an individual producer's expected yield and market price. Hazell and Scandizzo [p. 237] have shown that these assumptions generate a covariance matrix W with diagonal elements

$$4)\qquad w_{ii} = \sigma_i^2\, E[y_i^2] + p_i^*\, \delta_i^2$$

and off diagonal elements

$$5)\qquad w_{ij} = (\sigma_{ij} + p_i^* p_j^*)\, \delta_{ij} + mi\, m_j\, \sigma_{ij}$$

The first order conditions (equation 3) show that the expected output for the ith product is a function of expected yields, expected prices and the variances and covariances of yields and of prices, namely[1]

$$6)\qquad x_i\, m_i = m_i\, f(M, P, W)$$

To focus on the effects of price variability, assume that yields are either known with certainty or that the variability is so small that it can be disregarded. The variances and covariances of yields are therefore zero and $E[y_i^2]$ equals m_i^2. The diagonal and off diagonal elements of the W matrix simplify, respectively, to

$$7)\qquad w_{ii} = m_i^2\, \sigma_i^2$$

and

$$8)\qquad w_{ij} = m_i\, m_j\, \sigma_{ij}$$

Considering the case of two competing crops only, the inverse of W is easily derived and with the elements of M and P known, the enterprise levels x are obtained from equation 3. Multiplying enterprise levels by the crop yield gives the output level for each crop. Let the primary crop be designated with the subscript 1 and carrying out the appropriate calculations, output of that crop is

[1]Production rather than acreage is used since no acreage data on Pinto beans are published.

9)

$$x_1 m_1 = \frac{m_1^2 p_1^* w_{22}}{b(w_{11} w_{22} - w_{12}^2)} - \frac{m_1 m_2 p_2^* w_{12}}{b(w_{11} w_{22} - w_{12}^2)}$$

The numerators of each term may be divided into the denominators, canceling and separating each of the two terms to give

10)

$$x_1 m_1 = \left[\frac{b w_{11}}{m_1^2 p_1^*} - \frac{b w_{12}^2}{m_1^2 p_1^* w_{22}}\right]^{-1} - \left[\frac{b w_{11} w_{22}}{m_1 m_2 p_2^* w_{12}} - \frac{b w_{12}}{m_1 m_2 p_2^*}\right]^{-1}$$

The w_{ij} terms are substituted into the above expression and the yields in each term cancel leaving output as a function of four interaction terms between expected prices and their variances.

11)

$$x_1 m_1 = g\left[\frac{\sigma_1^2}{p_1^*}, \frac{\sigma_{12}}{p_1^* \sigma_2^2}, \frac{\sigma_1^2 \sigma_2^2}{p_2^* \sigma_{12}}, \frac{\sigma_{12}}{p_2^*}\right]$$

The first term shows that the effect of the crop price variance on the supply response is modified by the level of the expected crop price. The second term shows that the effect of the covariance between crop prices is modified by the level of the crop price and the price variance of the alternative crop. The remaining terms are somewhat less intuitive; however, they show that the price level of the alternative crop acts as a modifier on the supply response. For ease of later use, the four terms are referred to as IT1, IT2, IT3 and IT4, respectively. Each variable used is defined and identified specifically later when the preferred equations are considered.

Empirical Model and Results

The theoretical development in the preceding section is applied in an empirical model of supply response for Pinto beans in the U.S. Pinto beans are produced predominately in Colorado, Idaho and Nebraska and, to a lesser extent, in eight other states. The Pinto beans are characterized by cobweb-type fluctuations in prices and in production.[2] Figure 1 shows the average annual Colorado price for the years 1949 to 1975. The series exhibits considerable price fluctuations and changes in the variability of the fluctuations. In addition, a period-to-period price reversal pattern is apparent, especially in the post-1960s. Production moved regularly in the opposite direction to current price, with the exception of the extraordinary years 1973 and 1974.

A linear model of the general form

$$Q_t = \phi(P_t^*, C_t, R_t, W_t)$$

is used, where Q_t is the annual U.S. production of Pinto beans; P_t^* is the supply-inducing price of Pinto beans; C_t is the supply-inducing price of the competing crop; R_t is a vector of risk variables; and W_t is a weather index.

Goodwin's extrapolative expectations model was chosen as a suitable model to use

[2]All data were obtained from official U.S.D.A. publications.

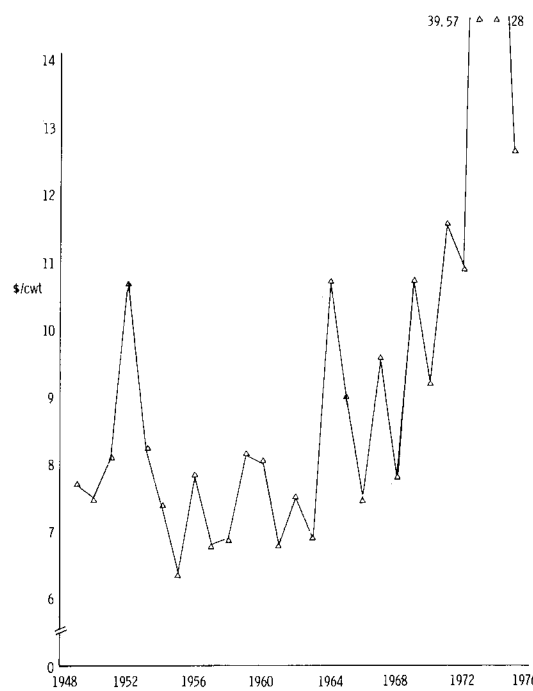

Figure 1. Average Annual Pinto Bean Price, U.S. No. 1 Colorado

as the specification of the supply-inducing price. Goodwin's model is

$$P_t^* = P_{t-1} + \beta(P_{t-1} - P_{t-2}) \text{ where } -1<\beta<1.$$

A negative β would reflect an expected reversal in price. Pinto beans were under a government loan rate program for most of the time. The support rate was generally well below the market price and attempts to include the loan rate as an explanatory variable gave insignificant coefficients and are not reported.

Many crops were tested as possible alternatives to Pinto beans. Sugar beets were eventually selected as the competing crop. The relative stability in the sugar beet price series was deemed sufficient to permit lagged price to be used as the relevant price. Since sugar beets were under government acreage quotas at times during the period investigated, a variation of the model included actual quota acres in Colorado and Idaho with a zero one dummy variable equaling one in the years in which quotas were not in force. These results were not successful in that the quota and dummy variables had incorrect signs and/or were not significant. Lagged sugar beet price alone was retained.

The vector of risk variables in the general model contained the IT1, IT2, IT3 and IT4 price interaction terms suggested by the preceding theoretical section. The price risk variables were initially constructed from the variances and covariances of Pinto beans and sugar beet prices over the three preceding years. The fixed weight lag scheme proposed by Fisher is used to weight these variance terms.[3] This scheme permitted more recent variations to have a greater weight, but avoided the estimation problems raised by the geometrically declining weights used by Just [1974].

After preliminary investigations the construction of the interaction terms continued with standard deviations in lieu of the variances in the IT1, IT2, and IT3 terms. The degree of the covariance terms in IT2 and IT4 is appropriately reduced, but the sign on the covariance term in IT4 is maintained. An example of the calculations undertaken is afforded by the construction of the PSD_t variable, the weighted standard deviation in year t.

$$PSD_t = [\sum_{k=1}^{3} w_k(x_{t-k} - \bar{x}_t)^2]^{1/2}$$

where x_{t-k} is the price in year $t-k$; $\bar{x}_t$ is the average price over the preceding three years to year t; and w_k is a Fisher lag of 1/2, 1/3 and 1/6 for $k = 1$, 2 and 3 respectively.[4] The interaction terms are readily calculated using the weighted price variability terms and the three-year average prices around which the variability terms are calculated as the modifying expected price. The rationale for specifying the expected prices in such a manner was to maintain consistency of expectations within the risk terms and to keep the estimation procedure as straightforward as possible.

Two alternative risk vectors containing a weighted standard deviation of bean prices and a ratio of the weighted standard deviations of bean prices to sugar beet prices, respectively, are also used in the empirical analysis. The use of the standard deviation as the risk variable conforms to the traditional approach of risk specification. The use of the ratio is similar to the specification used by Behrman [p. 158].

Although in the theoretical section yield risk was assumed away, a risk variable as suggested by Behrman was constructed. The variable is the standard deviation of Colorado yields around the three-year moving average.[5] Empirically, the coefficient was insig-

[3]The Fisher weights gave marginally better empirical results than an equal weighting scheme.

[4]Fisher lags over 4 and 5 year periods were tried. The 3 year lag gave the most satisfactory results. The results were not highly sensitive to the length of lag and definitely not as sensitive as the results reported by Traill's [p. 10] study of onion acreage response to risk.

[5]The only yield series available is a state series for dry edible beans as a group. Presumably, for Colorado, these yields apply to Pinto beans, which are virtually the only dry edible bean produced.

TABLE 1. Supply Equations (1953-1975) for U.S. Pinto Bean Production ('000 cwt)

Eq.	Const.	LPP	DPP	LSBP	IND	DW1	DW2	PSD	CFV	IP1	IP1*2	$\bar{R}^2$	D.W.	d.f.
1.	1,026	255.4	−148.5	−129.1	40.58	867.0	−404.8					0.71	2.14	16
		(2.75)	(3.06)	(1.92)	(3.33)	(2.90)	(1.60)							
2.	508	426.6	−123.3	−86.38	27.66	661.0	−607.0	−525.9				0.91	1.91	15
		(7.41)	(4.60)	(2.33)	(3.97)	(3.97)	(4.29)	(6.23)						
3.	2,321	442.2	−153.2	−182.2	26.19	525.9	−694.0		−7,769.3			0.86	1.68	15
		(5.79)	(4.61)	(3.83)	(2.93)	(2.41)	(3.76)		(4.39)					
4.	2,077	476.2	−150.7	−202.9	29.18	533.3	−680.4		−5,790.4	−2,941.5		0.92	1.49	14
		(7.86)	(5.80)	(5.38)	(4.14)	(3.12)	(4.72)		(3.83)	(3.25)				
5.	1,293	394.6	−68.5	−134.8	31.00	633.7	−546.60		−4,917.3		−360.0	0.93	1.87	14
		(7.22)	(2.20)	(3.82)	(4.86)	(4.08)	(4.08)		(3.46)		(4.08)			

|t| values in parentheses.

nificant. The matter was not further pursued due to the limited data and due to a visual appraisal of the time series of yields which indicated relatively constant variability over time. Another factor which may have hampered the delineation of yield risk as an explanatory variable is the inclusion of the June 1st pasture index as a weather variable. This variable likely accounted for most of the yield variation.

The preferred equations estimated from 1953 through 1975 are presented in table 1. Equation 1 contains no risk variables. Equation 2 contains the weighted standard deviation of the crop price as the risk variable.[6] Equations 3, 4 and 5 contain variations on the interaction terms which were suggested by the theoretical model developed earlier.

The variables which are contained in the preferred equations are

LPP — the price of Pinto beans (f.o.b. Colorado, U.S. No. 1) lagged one year in dollars per 100 lbs.

DPP — the difference between the prices of Pinto beans in years t-1 and t-2

LSBP — the average farm price of sugar beets, including government payments, in Colorado and Idaho, lagged one year, dollars per ton

IND — the average of June 1st pasture index for Colorado and Idaho

DW1 — a dummy variable equaling one in the "good" years 1961 and 1963 and zero in all others[7]

DW2 — a dummy variable equaling one in the "poor" years 1956, 1964 and 1973 and zero in all others[7]

PSD — a weighted standard deviation of the preceding three-years of Pinto bean prices around the preceding three-year average; the weights are 1/2, 1/3 and 1/6

CFV — a weighted coefficient of variation of Pinto bean prices determined by dividing the PSD variable by the preceding three-year average bean price (a variation on the IT1 variable in the theoretical section)

IP1 — the absolute value of the covariance of Pinto bean and sugar beet prices divided by the preceding three-year average of Pinto bean prices and divided again by the standard deviation of sugar beet prices (a variation on the IT2 variable in the theoretical section)

[6]The ratios of standard deviations gave insignificant coefficients and are not reported.

[7]In five years, as judged from crop conditions discussed in various monthly issues of the U.S.D.A. *Crop Production*, extreme weather conditions occurred which were not captured in the June 1st index.

IP1*2 — the square of the covariance of Pinto bean and sugar beet prices divided by the preceding three-year average Pinto bean price and divided again by the variance of the sugar beet price (a variation on the IT2 variable in the theoretical section)

The signs on the coefficients in all equations conform with *a priori* expectations. Goodwin's β coefficient is obtained by dividing the coefficient on DPP by the coefficient on LPP and is negative in all cases. The negative β indicates that the supply-inducing price is revised in the opposite direction to the recent price movement. Given the behavior of the Pinto bean price series [figure 1], the revision is in accordance with Goodwin's [p. 191] expectations. The magnitude of β exceeds one-half for equation 1, but is reduced to approximately one-third when a risk variable is included, as in equations 2, 3 and 4, and declines further to 0.17 for equation 5.

Including a risk variable in the equations increases the $\bar{R}^2$ value and the coefficient on the LSBP variable becomes significant at the 5 percent level. The coefficient on the weather variable, IND, also declines. The risk variables have negative coefficients indicating that an increase in price variability has a depressing effect on the supply of Pinto beans. The specification of the coefficient of variation (CFV) variable permits a differential response to price variability. The supply-reducing response is modified at high recent prices and has a larger effect at low recent price levels. In contrast, the standard deviation (PSD) variable implies the same response to price variability irrespective of recent price levels. The IP1 and the IP1*2 variables of equations 4 and 5 permit an interaction between the covariance of the crop prices, the variability of sugar beet prices and the level of Pinto bean prices. High price levels of Pinto beans in recent periods or increased variability of sugar beet prices will modify the supply-reducing response. Conversely, a *ceteris paribus* increased variability of Pinto bean prices as reflected in the covariance term will cause a greater supply-reducing response.

The other two interaction terms IT3 and IT4 suggested by the theoretical model were not empirically important in equations containing all four interaction terms. This result held whether all four terms were specified in variance or in standard deviation form. A simple correlation coefficient of 0.98 indicated a close association between IP1*2 and the IT4 variables specified as the covariance divided by the competing crop price. Equation 5, containing IP1*2, is reported in preference to the equation with IT4, because it has a slightly higher $\bar{R}^2$ and the IP1*2 variable incorporates the variability of the competing crop price as well as the covariance.[8]

The short-run price elasticity of supply of Pinto beans is not readily obtainable because lagged price enters the risk variables in a non-linear fashion. The elasticity depends on the coefficient on LPP, the coefficient on DPP, the coefficients on the risk variables and on the first derivatives of the risk variables. Generalizations from the first derivatives are not obvious due to the use of ratios, to terms of differing signs, and to terms whose signs depend on the price relationships over the preceding three years. The sense of the elasticity response from the risk variables is that if the small change in price is perceived to increase price risk, then the change will induce a smaller, less elastic price response given the negative sign on the risk coefficients. A less inelastic response may be expected if the price change is perceived to decrease the price risk. The supply elasticities from all equations are presented in Table 2. The equation without a risk variable has a low elasticity. Using the elasticity from that equation would substantially underestimate the supply response. The first derivatives of the risk variables were all posi-

[8]The consistency in the degree of the interaction terms is not maintained in equation 5, in which CFV contains a standard deviation and IP1*2 contains variances and covariance squared.

TABLE 2. Pinto Bean Short-Run Supply Elasticity 1975

Eqtn.	1	2	3	4	5
Elast.	0.47	1.19	1.02	1.03	1.15

tive for 1975. The supply response is accordingly more inelastic than if there were no response to risk. The response in other years will differ due to different price-quantity combinations and due to different three-year price histories.

Projections for 1976 indicate the quantitative importance of the risk variables. Table 3 indicates the response net of the risk variables and the effect of introducing each risk variable. To distinguish between alternative regression models, Kmenta [p. 404] suggests calculating a forecast interval at a given level of probability for each equation. An additional observation on the dependent variable will fall within the forecast interval corresponding to the correct model with the given level of probability. If the additional observation falls outside the forecast interval, then there is some justification for rejecting that model. The 95 percent confidence interval for each risk model is given in Table 3. The U.S.D.A. *Crop Production: Annual Summary* gives the 1976 Pinto bean production at 5,716 thousand cwt. The 5,716 figure lies outside the PSD (equation 2) confidence interval, but falls within the confidence intervals for the other models. Projections with equations 3 and 4 are very close to the actual production level.

Figure 2 plots the actual Pinto bean production levels and the estimated production levels from the no-risk variable equation 1 and a risk variable equation 5. The equation with the price risk variables is clearly superior to the no-risk variable equation, particularly in the later years. The decrease in production in 1976, which lies outside the estimation period, is predicted by the risk variable equation but is missed by the no risk equation. The decrease in 1976 production is predicted by all risk equations (see Table 3), although the PSD equation 2 apparently over-responded.

Concluding Comments

The intention of this study was to develop a risk model for estimating the aggregate supply response of Pinto beans. A simple model of producer behavior under uncertainty was used to suggest appropriate variables. The risk variables in the preferred equations have intuitive explanations and they suggest plausible behavioral responses by producers. The study revealed that risk response is quantitatively important in the production of Pinto beans and that omitting the risk response would significantly bias the supply response. Any policy initiatives undertaken to reduce the price fluctuations of Pinto beans should take into account the supply-increasing effects of such a reduction. Failure to do so would result in a lower, albeit more stable equilibrium price than would be expected, and perhaps larger price support payments. While not tested empirically, these results may be generally applicable to risk-reducing policies considered for other farm crops.

TABLE 3. The Supply Response in 1976 ('000 cwt)

	Net of risk	Risk variables effect					95% c.i.	
Eqtn.	variables	PSD	CFV	IP1	IP1*2	Estimate	Lower	Upper
1	6,466					6,466	5,303	7,629
2	8,868	−4,714				4,154	3,150	5,158
3	8,307		−2,460			5,839	4,993	6,685
4	8,251		−1,840	−590		5,821	5,162	6,478
5	7,345		−1,562		−378	5,405	4,767	6,041
Actual 1976						5,716		

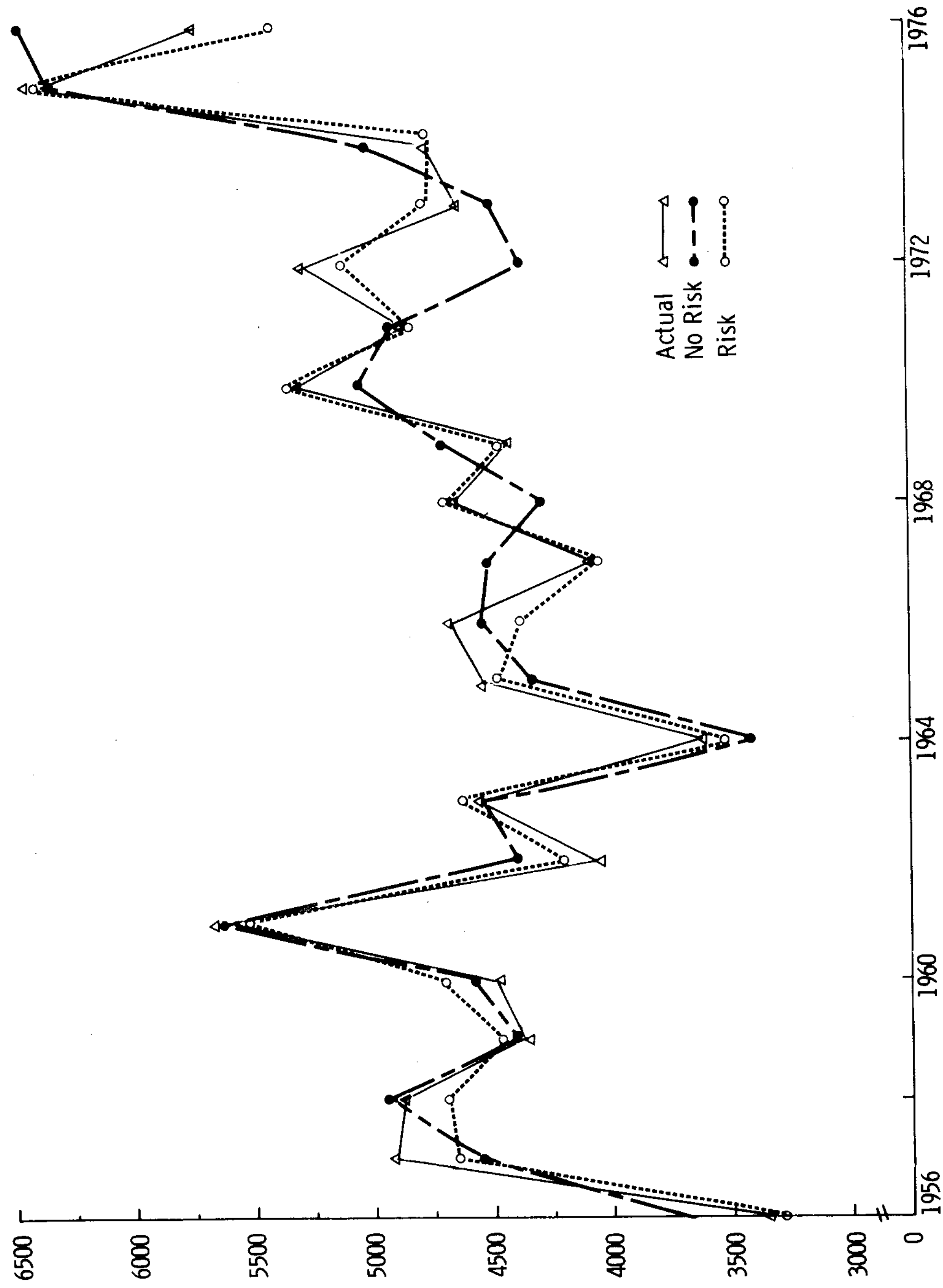

Figure 2. Actual Pinto Bean Production and Estimates from the No Risk Equation (1) and a Risk Equation (5)

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