An Econometric Evaluation of Stabilization Policies for the U. S. Grain Market

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This paper evaluates stabilization policies by applying methods of stochastic control and dynamic analysis to an econometric model of the U.S. grain market. Its main results are: (1) the aggregate consumer and producer surplus generated by the model is insensitive to the choice of the market regime; (2) policies directed to stabilize prices at levels compatible with nondecreasing farm revenue require the management of both grain inventories and domestic supply; (3) price fluctuations are significantly less under optimal stabilization than in the unregulated version of the model; and (4) historical policies have destabilizing effects on the market model.

How to stabilize grain prices, if at all, is an old but still unsolved policy problem. The present paper studies this matter by applying methods of stochastic control and dynamic analysis to an annual econometric model of the U.S. grain market. This approach has several advantages over more traditional analyses of grain market regulation:[1] (1) it is based upon a model of the market that explains the underlying dynamic phenomena; (2) the model takes into account feedback effects due to supply and private stock response to stabilization efforts; (3) the decision rules used in the analysis are optimal with respect to explicit welfare criteria; and (4) measures of stochastic dynamic performance offer a clear cut comparison of alternative market regimes. Most previous studies are based upon historical trend analysis or upon simulation. Most simulation studies use *ad hoc* specifications rather than a statistically estimated market model.

An Annual Model of the U.S. Grain Market

Structural Equations

The model is based upon received theory and the insights provided by previous studies [Cromarty; Egbert; Houck and Ryan; and Nerlove, in particular]. The individual equations are presented in Table 1, which includes the estimated regression coefficients, the ratio of each regression coefficient to its standard error, the multiple correlation coefficient (R^2)[2], the Durbin-Watson statistics (DW) of the supply equations, and the

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[1]See, for example, Fox and Wells; Gustafson; Waugh; Tweeten, Kalbfleish, and Lu; Bailey, Kutish and Rojko; Hillman, Johnson and Gray; Ray and Moriak; and the papers presented at the 1976 ORSA-TIMS Conference on the Systems Analysis of Grain Reserves, compiled by Eaton and Steele. Contributions which apply optimal control theory to agriculture econometric models include: Rausser and Freebairn; Talpaz and Taylor; and Arzac and Wilkinson (1979b). The state of the subject is surveyed in Rausser.

[2]We report the R^2 statistic for two-stage-least squares results. The high value of R^2 is an unambiguous indication of good fit even when its range is $(-\infty, 1]$.

TABLE 1. Econometric Model of the U.S. Grain Market

	Consumption Equations		
(1)	$c_1 = \underset{(3.63)}{798.3} - \underset{(-2.83)}{.7080}\, p_1 + \underset{(1.14)}{.6637}\, p_2 + \underset{(2.68)}{.4351}\, c_{1,-1} - \underset{(-1.53)}{.3681}\, p_{1,-1} + \underset{(2.09)}{.2266}\, n - \underset{(-2.33)}{12.30}\, t$	$\rho = -.20$	$R^2 = .86$
(2)	$c_2 = \underset{(4.20)}{6511} + \underset{(.96)}{1.856}\, p_1 - \underset{(-3.36)}{13.76}\, p_2 + \underset{(2.08)}{.5725}\, c_{2,-1} - \underset{(-2.73)}{5.986}\, p_{2,-1} + \underset{(3.74)}{2.550}\, n - \underset{(-2.59)}{124.7}\, t$	$\rho = .29$	$R^2 = .94$
	Inventory Equations		
(3)	$s_1 = \underset{(8.06)}{765.1} - \underset{(-4.94)}{2.062}\, p_1 - \underset{(-3.29)}{.1761}\, m_1$	$\rho = .29$	$R^2 = .75$
(4)	$s_2 = \underset{(11.5)}{2483} - \underset{(-7.46)}{10.83}\, p_2 - \underset{(-4.38)}{.2582}\, m_2$	$\rho = .22$	$R^2 = .76$
	Supply Equations		
(5)	$q_1 = \underset{(-4.21)}{-2029} + \underset{(5.51)}{2.291}\delta\, p_{1,-1} + \underset{(3.04)}{2.089}(1-\delta)\pi_1 - \underset{(-2.75)}{5.015}\,(1-\delta)d_1 + \underset{(3.62)}{982.2}w_1 + \underset{(9.58)}{33.67}\, t$	DW = 1.94	$R^2 = .88$
(6)	$q_2 = \underset{(-3.42)}{-7590} + \underset{(1.52)}{4.815}\delta\, p_{2,-1} + \underset{(1.46)}{5.881}(1-\delta)\pi_2 - \underset{(-.96)}{.7338}\, p_{3,-1} + \underset{(3.15)}{3296}\, w_2 + \underset{(7.68)}{150.9}\, t$	DW = 1.76	$R^2 = .89$
	Identities		
	$c_i + e_i + f_i + s_i + m_i - s_{i,-1} - m_{i,-1} - q_i = 0 \quad i = 1, 2$		

first-order autocorrelation coefficients (ρ) of the disturbances in the simultaneous block of consumption and inventory equations. The variables are: c_i = domestic consumption (i = 1 for wheat and i = 2 for feed grain prices); s_i = domestic commercial inventories at the end of the crop year; q_i = domestic supply; e_i = net commercial exports; f_i = concessional exports; m_i = government stocks at the end of the crop year; p_i = average market price (i = 3 for soybeans); π_i = weighted support price; d_i = weighted acreage diversion rate; n = U.S. disposable income per capita for the calendar year (mill. 1958dol.); w_i = index of weather conditions; t = time index (t = 47, 48, . . .); and δ = dummy variable, $\delta = 1$ for 1947-48 and 1973-75, and $\delta = 0$ for 1949-72.

Domestic consumption, commercial inventories, domestic supply and the market prices of wheat and feed grains are endogenous. Exports, government stocks, support prices, diversion rates, disposable income, weather and a time trend are exogenous.

Quantities are expressed in million bushels and correspond to crop years. Feed quantities include corn, grain sorghum, barley and oats, and are expressed in corn equivalents obtained using 1962 relative market prices as weights. Prices are expressed in cents of 1967 per bushel. Support and diversion rates are weighted by the restrictions imposed on program participants as in Ryan and Abel. Feed grain prices are aggregated using the fractions of 1962 total feed grain output as weights. The indexes of weather conditions are the ratios of actual to normal yields per acre which, as in Egbert, follow quadratic trends.

Equations (1) and (2) are partially reduced demand for grain equations which attempt to take into account the determinants of equilibrium in final and intermediate food markets. These equations can be interpreted as representing a partial adjustment process with equilibrium demand determined by current and lagged market prices, real disposable income per capita, and a time trend.[3] Equations (1) and (2) can also be justified in terms of the following alternative, perhaps more satisfactory model: demand for food, D_f, is a function of current food price, P_f, and shift variables, Z. Supply of food, S_f, depends on the lagged prices of food and grain.[4] Demand for grain, D_g, is a derived demand with supply of food and the current price of grain, P_g, as arguments. That is,

$$(7)\, D_f = D_f(P_f, Z)$$

$$S_f = S_f(P_{f,-1}, P_{g,-1})$$

$$D_g = D_g(S_f, P_g),$$

where all functions are assumed to be linear in the variables. Upon substituting S_f into (7) and using the food market clearing condition, $D_{f,-1} = S_{f,-1}$ to solve for $P_{f,-1}$ and eliminate it from (7) one obtains

$$(8)\, D_g = D_g(P_g, P_{g,-1}, P_{g,-2}, P_{f,-2}, Z_{-1}).$$

After successive substitutions to eliminate $P_{f,-2}$, $P_{f,-3}$, . . ., (8) becomes a function of infinite distributed lags with geometrically declining weights in grain prices and the shift variables, which can be rewritten in the form of equations (1) and (2).[5] The reduced form specification of grain consumption permits studying grain price fluctuations without having to model and estimate the livestock mar-

[3]Because of collinearity, the effect of population cannot be separated from the negative trend which is partly due to changes in taste and processing technology. Previous studies of U.S. grain and food consumption have faced a similar difficulty. For example, Tweeten (p. 351) excludes population effects and explicitly allows for a trend. Cromarty (pp. 562-563) does not use a trend, but his model ignores population and contains apparently unwarranted regressors in lieu of trend.

[4]This is particularly true of livestock production where the supply of meat depends on previous breeding decisions based upon previous prices. See Arzac and Wilkinson (1979a).

[5]See Johnston (pp. 300-303), for example. Strictly, equations (1) and (2) are an approximation to this formulation because they include current income only, rather than a distributed lag on this variable, and the disturbances are assumed to follow simple first-order serial correlation.

ket. The price of this simplification is not small, however, since no direct information about livestock market fluctuations can be provided.[6]

The specification of the rest of the model is straightforward. The private inventory equations (3) and (4) are a function of current prices and government stocks. Futures prices and lagged spot prices are not included following Working's observation that the spot price of a commodity with continuous storage such as grain contains all the relevant information. Tomek and Gray have further developed and tested this notion. See also Labys and Granger (Ch. 4). Grain supply depends on expected prices at planting time, weather conditions and technological change. Expected prices are functions of market prices at planting time when these are above support rates. Otherwise, government programs determine the farmers' expected prices as in Houck and Ryan. The market price of soybeans is included in the feed grain supply equation because soybeans are a production substitute for feed grains [Houck, Ryan and Subotnik].

Equations (1) through (4) were estimated with 1947-73 data by a two-stage least square procedure for simultaneous equations with autoregressive residuals [Fair].[7] Equations (5) and (6) were estimated with 1947-75 data by ordinary least squares. The dummy variable δ used in these equations distinguishes those years when supply responded to market prices ($\delta = 1$) from those years when supply responded to government programs ($\delta = 0$).

Price and income elasticities are smaller in the case of wheat consumption, consistent with the fact that the latter is mostly derived from general food demand, while feed grain consumption is mostly derived from fed meat demand.[8] General food demand is less price and income elastic than fed meat demand [Tweeten and Arzac and Wilkinson (1979a)]. The cross-price elasticity of wheat consumption is also larger, reflecting the sensitivity of wheat feeding to the wheat-feed grain price relationship.

The acreage diversion rate was excluded from the feed grain supply equations because it had a positive and insignificant coefficient which changed erratically with the size of the sample. We concluded that, in spite of its apparent effect on corn acreage [Houck and Ryan], the effect of acreage diversion programs on total feed grain output was negligible. This may be due to the fact that the programs applied mainly to corn and, in several years, admitted planting other feed grains in acreage diverted from corn. Another reason has been given by D. G. Johnson (pp. 34-35) who points out that, since the features of the grain programs were changed on the basis of anticipated market conditions, it is very difficult to distinguish between the effects of acreage diversion and market conditions. Lagged output was not found to be a statistically significant explanatory variable for either grain and had the wrong sign in the feed equation, suggesting that postwar supply response is not subject to delayed adjustment. Finally, we note that, while aggregating over feed grains might have masked the effect of price on supply, the results of this paper are not sensitive to significant increases in the price elasticity of feed supply.[9]

[6]For estimation and analysis of the livestock market see Arzac and Wilkinson (1979a, 1979b).

[7]The specification of the demand equations in the simultaneous block implies autocorrelated disturbances [Johnston (pp. 300-303)]. The system is identifiable even in the presence of autocorrelation: it satisfies Fisher's (pp. 168-175) condition as well as the usual rank condition for identifiability (*ibid.* pp. 21-36).

[8]The short-run elasticities of consumption at sample means are:

	Price	Cross Price	Income
Wheat	−.23	.13	.71
Feed Grain	−.63	.052	1.14

Long-run elasticities are about twice as large.

[9]The elasticities of supply at sample means are:

	Market Price	Support Price	Soybean Price	Diversion Rate
Wheat	.38	.25	--	−.079
Feed Grain	.16	.11	−.04	--

Reduced Form Fit and Ex-post Forecasting Performance

The reduced form of the model (i.e., current endogenous variables as functions of predetermined variables) was derived from the structural equations of Table 1 and its performance evaluated over the sample period and a one year ex-post forecast.[10] Theil's (pp. 31-46) normalized mean-squared error (U) and the multiple correlation coefficient (R^2) between actual and predicted values were computed. The ranges of U and R^2 were [.01, .08] and [.84, .94], respectively. As expected, consumption and output performed better than stocks and prices, but the model tracked recent stock and price fluctuations quite well.

Exogenous variables

The evaluation of stabilization policies requires making assumptions about the behavior of the exogenous variables. Grain exports, which were not found to respond to prices in this study (perhaps because of their pronounced dependency on weather and government policies in the rest of the world,[11]) are assumed to be a function of previous exports and a time trend, with disturbances following first-order serial correlation to allow for possible movements in phase of omitted variables. The following export equations are estimated by generalized least squares with 1947-72 data:

$$(9)\quad e_1 = \underset{(-1.98)}{-342.4} + \underset{(2.10)}{.6748}\, e_{1,-1} + \underset{(2.10)}{7.22}\, t,$$

$$\rho = -.627,\ R^2 = .423,$$

$$(10)\quad e_2 = \underset{(-1.80)}{-877.0} + \underset{(2.80)}{.6826}\, e_{2,-1} + \underset{(1.85)}{17.63}\, t,$$

$$\rho = -.010.\ R^2 = .826.$$

Per capita disposable income is assumed to grow at the average rate observed during 1947-72, and the soybean price is fixed at its 1947-75 average. Data for 1947-75 were used to estimate the means and covariance matrix of the weather indexes.

The Stochastic Dynamics of The Unregulated Market

We now consider the stability and stochastic dynamic behavior of the unregulated market as characterized by the model of Table 1. The effects of government intervention are eliminated by letting $m_1 = m_2 = 0$ in (3) and (4), and $\delta = 1$ in (5) and (6). Furthermore, export equations (9) and (10) are appended to the model. The resulting system is stable. That is, the characteristic roots of the reduced-form coefficient matrix of lagged endogenous variables have moduli less than one.[12] Complex and negative characteristic roots contribute damped cycle components of 5.1 and 2 years, respectively, to the paths of the endogenous variable. When activated by random fluctuations, these cycle components produce sustained cyclical behavior. In fact, taking into account the disturbances of weather, exports and the endogenous variables, one can compute the steady-state standard deviations and the expected times between successive relative maxima of the time series (the latter are measures of the average length of cyclical fluctuations, see Chow (1975, pp. 47-48)). These measures are presented in Table 2, which shows that the model exhibits 2.7 to 3.7 year cycles similar

[10]The ex-post forecast periods are 1975/76-1976/77 for supply, and 1974/75-1975/76 for the rest. Ex-post forecasts are based upon data reported in the November 1976 issues of *Wheat Situation* and *Feed Situation*.

[11]Measurement errors in foreign data and the heterogeneity of grain importing countries might also be responsible for our inability to observe a price elastic demand for exports. Disaggregated estimation over groups of countries might make grain exports partially endogenous. The foreign data problem is discussed in Hooper and Underwood, who report preliminary estimates of aggregate grain export equations with insignificant price coefficients.

[12]The procedure for writing a linear system with autocorrelated residuals in first-order form is discussed in Chow [1975, pp. 21-22 and 61-63].

TABLE 2. Stochastic Behavior of the Unregulated Market Model

Variable[a]	Level in 1974/75	Standard deviation	Cycle length in years
Wheat consumption	683	66	3.54
Feed grain consumption	4779	383	3.74
Wheat commercial stocks	318	182	2.73
Feed grain commercial stocks	558	282	3.06
Wheat price	248	93	2.66
Feed grain price	167	28	2.96
Wheat supply	1793	265	2.64
Feed grain supply	5931	491	2.83
Wheat exports	1037	151	2.70
Feed grain exports	1403	198	3.61

[a]Quantities are expressed in million bushels and prices in cents of 1967.

to those reported for most economic variables in the business cycle literature.

The standard deviation of feed grain prices is substantially smaller than the standard deviation of wheat prices, which agrees with casual observation and suggests that wheat prices will demand the greatest stabilization effort. Further insights into the dynamic behavior of the model are given by the implied power spectra of exports and prices presented in Figure 1, which measure the contribution of the random periodic components of different frequencies to the total variance of the series. [Chow (1975, pp. 78-80 and 85-87)]. Wheat exports have more power than feed grain exports at high frequencies. Furthermore, the spectrum of wheat prices is above that of feed grain prices throughout the frequency domain and increases at high frequencies, indicating distinct short cycles. The partial coherences of prices with exports (not reported here) show that both short and long term export fluctuations have strong effects on wheat prices, but only mild effects on feed grain prices.[13]

The Stochastic Control Problem

Control theory provides a natural characterization of optimal government policy: a feedback control function to steer the economic system toward desired targets. In the model of this paper endogenous prices and quantities are functions of such exogenous variables as income, weather and commercial exports, and of such policy instruments as government stocks, concessional exports, and support prices. Uncertainty, due to equation disturbances and to the stochastic behavior of weather and exports, requires defining opti-

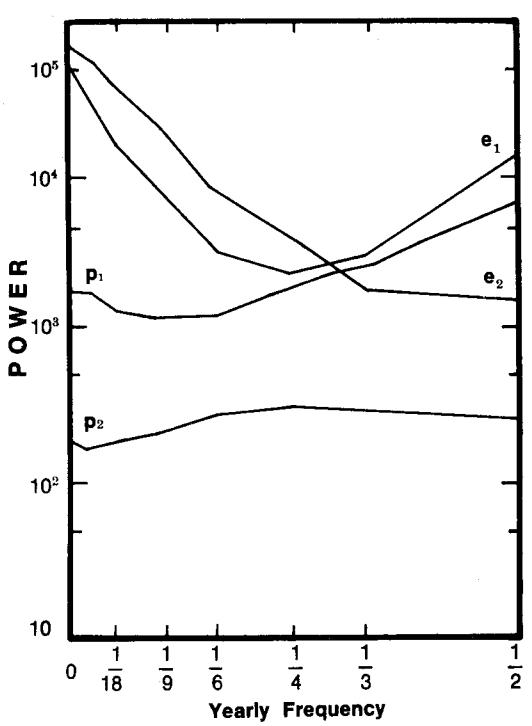

Figure 1. Power spectra of grain exports and free market prices.

[13]Details are given in Arzac. The partial coherence is the squared partial correlation coefficient between the same frequency components of two series [Labys and Granger, pp. 54-56].

mality in terms of the expected value of some criterion. Two alternative criteria are considered in this paper: (1) The expected domestic surplus, defined as the area under the demand curves, minus the area under the supply curves, plus export revenues, minus the cost of private and government inventories;[14] and (2) a weighted sum of mean-squared-deviations of selected variables from their prespecified targets. As in the macroeconomic stabilization literature (see Chow (1975) and Pindyck for example), weights and targets will be varied in order to derive and evaluate alternative stabilization policies.

In order to state and relate the stochastic control problems corresponding to the above criteria one notes that the reduced form of the market model plus the equations describing the paths assumed for the uncontrolled exogenous variables can be compactly written as

$$y_t = Ay_{t-1} + Cx_t + \epsilon_t, \tag{11}$$

with given initial condition y_o, where y_t is the vector of *all* endogenous and exogenous variables and autocorrelated disturbances, x_t is the vector of the exogenous variables used as policy instruments and ϵ_t is the vector of uncorrelated disturbances. A and C are coefficients matrices (see footnote 12).

Using the structural form of the model to compute the surplus areas and approximating storage costs by a quadratic function, one obtains the following quadratic surplus function

$$E \sum_{t=1}^{T} \alpha^t y_t' K y_t , \tag{12}$$

where E is the expectation operator, $\alpha \in (0, 1]$ is a discount factor, $t = 1, \ldots, T$ is the control period and K is a negative definite matrix of coefficients. y_t' is the transpose of y_t.

On the other hand, the quadratic specification of criterion (2) is

$$E \sum_{t=1}^{T} (y_t - a_t)' K_t (y_t - a_t) , \tag{13}$$

where a_t is a target vector for period t, and K_t is a positive definite matrix of assigned weights. Chow (1975, pp. 156-180) has shown that the minimum of (13) subject to (11) is the linear feedback function

$$x_t = G_t y_{t-1} + g_t , \tag{14}$$

where G_t and g_t satisfy a system of difference equations. Moreover, we note that the surplus maximization problem (maximize (12) subject to (11)) can be solved as a loss minimization problem by simply letting $a_t = 0$ and $K_t = -\alpha^t K$ in (13).

Welfare Optimal Regulation Versus The Unregulated Market

Does private inventory holding maximize expected domestic surplus, or are there significant welfare gains to be attained by complementary government regulation of grain stocks? To answer this question we derive surplus-maximizing policies (criterion (12)) using government stocks as sole policy instruments, and compare their performance against the unregulated market version of the model.

The elements of K are computed in Arzac using Hotelling's surplus measure for related commodities. Storage costs are approximated using data provided by Schienbein for the cost of storage at commercial elevators. Short-run marginal costs (2.61 cents of 1967 per bu.) are his variable costs minus taxes. Long-run marginal costs (6.77 cents per bu.) are his replacement costs minus taxes. The quadratic storage cost functions are assumed to attain their minima at the carryover level observed at the end of 1972, that is, at 294 million bushels (m.bu.) of wheat and 1103 m.bu. of feed grains. These values are assumed to be the points where the unobservable marginal "convenience yield" of processors and traders equates the marginal cost of physical storage. Full long-run marginal costs of physical stor-

[14]Note that the international surplus is not defined in the absence of price elastic export demand functions.

age are attained at the carryover capacity of the economy, which is assumed to be equal to the maximum carryovers observed during the postwar period: 1411 m.bu. of wheat and 3000 m.bu. of feed grains in 1960. We note that the results reported in this section are not dependent upon the crude approximation to the storage cost function implied by these assumptions.

Optimal steady-state policies, approximated by the tenth iteration on the optimality conditions, are used to characterize the optimally regulated market. They correspond to an infinite horizon and are not subject to truncation effects. Expected trajectories are computed iteratively using the reduced form of the model with and without the control equations. Expected surplus is computed using a formula developed by Chow (1975, p. 167).

The expected trajectories are not reported. They show that the regulated market tends to accumulate larger wheat inventories and increase prices. But higher export revenues are offset by lower domestic consumption and higher inventory costs. In fact, in spite of the assumption of price inelastic exports which is biased against the unregulated market, the latter performs almost as well as the regulated market in terms of expected surplus. The expected surplus per year is $84.05 billion in 1967 dollars for the unregulated market and $84.97 billion under the optimal policy corresponding to no discounting ($\alpha = 1$ in (12)).

The yearly surplus should not be compared to the value of annual output of wheat and feed grains. In fact, because of the low price elasticities of the demand for grain, the surplus is about four times as large as the value of output. The present value of the surplus generated over ten years (discounted at ten percent) is $502.4 billion in the unregulated market and $510.2 billion under the optimal policy corresponding to ten percent discounting ($\alpha = (1.1)^{-1}$ in (12)). These differences of about one percent in the surpluses generated by the two regimes seem small and are likely to be within the margin of error of the present study. Moreover, the unregulated market continues to perform almost as well as the optimally regulated market under significant changes in the market model and the welfare function, including a ten-fold increase in storage costs, a three-fold increase in the feed grain price coefficient of the feed grain supply equation (see footnote 9), and a two-fold lengthening of the horizon.

The unregulated market is not unique in approximating the performance of optimal regulation. Changes in the coefficients of the optimal policies did not produce significant departures either, suggesting that expected surplus is rather insensitive to the form of the inventory policy. Policy makers might then be able to pursue such goals as price stability and farm income maintenance without incurring significant aggregate welfare costs. This possibility is examined in the following section.

Optimal Stabilization Policies

Stabilization Through Inventory Management

In this section optimal price stabilization policies are obtained and compared to the unregulated market. The loss function (13) is adopted as a criterion. Target prices are set above the declining trends produced by the unregulated market in order to force stabilization policies to maintain farm income. The latter is perhaps the most binding constraint faced by policymakers (the last column of Table 3 below shows that farm revenue decreases in the unregulated market). The purpose of this experiment is to find out if a grain stock policy can reduce price fluctuations and maintain farm income without requiring excessive inventories and without decreasing aggregate surplus.

Several alternative stabilization policies are considered. Policy 1 is obtained by minimizing the sum of the yearly mean-squared deviations (MSD) of prices from their 1972 levels (178.2 cents for wheat and 126.2 for feed grains). As expected from a policy attempting to maintain prices above

their free-market level but subject to no inventory penalty, this policy requires a large accumulation of stocks. As Table 3 shows it succeeds in tracking the price targets but average government inventories are 3129 million bushels (m.bu.) of wheat and 3775 m.bu. of feed grains.

Policies 2 and 3 attempt to reduce the expected size and variance of government inventories by introducing the weighted MSD of their levels about zero in the criterion function, with weights equal to .001 in policy 2 and .0001 in policy 3. Policy 2 reduces expected inventory levels but fails to obtain the price targets. Policy 3 approaches the price targets but requires an average wheat inventory of 2648 m.bu.

The results of additional experimentation agree with the implications of policies 2 and 3: maintaining wheat prices near the level of 1972 with stocks as sole instruments requires an excessive accumulation of wheat inventories. An alternative price target equal to 140 cents per bushel of wheat is used in deriving policy 4. Under this policy average wheat stocks are 1759 m.bu. and the average wheat price is 124 cents. The last column of Table 3 shows that policy 4 maintains farm revenue.

From the penultimate column of Table 3, we conclude that price support and stabilization policies do not reduce aggregate surplus in the present model. The stabilization gain attained by policies 1 through 4 is very modest, however. In fact, the standard deviation of wheat price under optimal control is only 17 percent below its free-market value. One reason is that inventory management has so far been based upon previous year information. The stabilization gain attained by policies which make use of current year information will be considered below.

TABLE 3. Statistical Characterization of Grain Market Regimes During 1976-1985[a]

Regime	Wheat Price		Feed Grain Price		Wheat Stocks		Feed Grain Stocks		Wheat Disposals		Feed Grain Disposals		Consumer and Producer Surplus	Growth of Farm Revenue
	Bias[b]	Std. Dev.	Bias	Std. Dev.	Bias	Std. Dev.	Bias	Std. Dev.	Bias	Std. Dev.	Bias	Std. Dev.		
Free Market	−126.6	92.4	−20.5	27.0									84.05	−2.0
Policy 1	0.0	76.9	0.0	24.6	3129	328	3775	1280					84.67	2.0
Policy 2	−96.8	77.8	−17.7	26.1	729	205	−61	89					84.39	−1.2
Policy 3	−24.0	77.0	−11.0	25.3	2648	307	239	298					84.91	1.1
Policy 4	−16.3	77.0	−13.7	25.3	1759	307	218	298					84.78	0.2
Policy 5	.2	76.9	−.5	24.6	−221	13	−17	33	44	100	210	255	85.06	2.0
Policy 6	−.7	76.9	−4.3	25.5	−102	63	−17	46	29	66	17	44	85.26	1.9
Policy 7	−.7	33.4	−4.3	17.0	−102	115	−17	152	29	131	17	93	84.79	1.9
Historical Policy[c]	19.2	103.1	−4.6	39.5	7	261	143	405	−273	37	−123	7	85.75	2.1

[a]Prices are expressed in cents of 1967, stocks and disposals in million bushels, surplus in billion dollars of 1967 per year, and growth of farm revenue in annual rates.

[b]The bias is the 10 year average of the difference between the expected value and the target value of the variable.

[c]Evaluated with respect to the targets of policies 6 and 7.

Stabilization Through Inventory Control and Grain Disposals

We now introduce two new policy instruments (one for each grain) which enter the market clearing equations of the model as

disposals of excess grain. Disposals can be interpreted as concessional exports or as supply reductions. Under the first interpretation, the revenue from concessional exports is assumed to be negligible. Furthermore, these exports are assumed to go to segmented markets which do not interact with the commercial export market. Of course, a set of refined export equations would make this last assumption unnecessary (see footnote 11). Alternatively, the optimal disposal levels can be attained by reducing supply through supply-related instruments (support prices and the diversion rate appearing in equations (5) and (6)).

Target prices are set at their 1972 levels. Positive targets are assigned to inventories and disposals to penalize relatively more negative deviations since now, given the increase in the number of instruments, maintaining prices on the high side is not sufficient to force the instruments to assume positive values. The targets are: 400 million bushels (m.bu.) for wheat stocks, 300 m.bu. for feed grain stocks, 400 m.bu. for wheat disposals and 200 m.bu. for feed grain disposals.

Three stabilization policies are considered. Policy 5 assigns weights 1, .001 and .00005 to the MSD of prices, stocks and disposals, respectively. Policies 6 and 7 assign weights 1, .002 and .005, respectively. Their statistical implications are presented in Table 3. Policies 5 and 6 reduce the standard deviations of prices almost as much as policy 1 but require much smaller expected inventories — in the 200-300 m.bu. range. This is due to the use of disposals, the expected level of which is in the 200-400 m.bu. range. Disposals maintain prices above their free-market level, but their large standard deviations indicate that they are also largely responsible for stabilization in the case of policy 5. This may not be desirable if disposals are concessional exports, or may not be feasible if they are supply reductions. A more balanced alternative is offered by policy 6 where both inventories and disposals share responsibility for stabilization. Further reductions of the standard deviations of disposals can be obtained by increasing their weights in the loss function. Policy 7 adjusts the instruments according to information regarding current supply and export disturbances. As expected, it results in more active intervention and attains significant reductions in the standard deviations of both prices.

One notes that the surpluses obtained by policies 5 and 6 are slightly above that obtained by the surplus maximization inventory policy of the preceding section. By using grain disposals, policies 5 and 6 maintain prices above their free-market level with small inventory costs. Moreover, the surplus figures of Table 3 do not give any value to disposals. Interpreting disposals as supply reductions lowers supply costs by about one billion dollars and increases the surplus to about 86 billion dollars per year. Additional computations indicated that this figure is also attainable by a surplus maximizing inventory *and* disposal policy, or by the free market when the export equations (9) and (10) are modified to make exports as price elastic as domestic consumption.

Evaluation of Historical Policies

Postwar agricultural policy has attempted to maintain prices above their free-market equilibrium by a combination of supply management, concessional exports, and passive inventory holding. Table 4 presents ordinary least squares estimates of linear government reaction functions for support prices, acreage diversion rates, concessional exports and inventories. Admittedly, characterizing more than two decades of heterogeneous policies by simple linear equations is a gross simplification. Still, the reaction functions of Table 4 have suggestive implications which seem worth a brief comment.

In order to evaluate the effects of historical policies on the performance of the grain market model, equations (15) through (17) are substituted into the supply equations (5) and (6) with $\delta = 0$ to obtain supply behavior under government supply management, (18) and (19) are used as the control equations for

TABLE 4. Observed Government Reaction Functions

		R^2	Sample
(15)	$\pi_1 = -17.64 + .7907\, p_{1,-1}$ $(-.63) \quad (6.23)$	.62	1949-72
(16)	$\pi_2 = -13.07 + .8710\, p_{2,-1}$ $(-.90) \quad (8.21)$	.74	1949-72
(17)	$d_1 = 14.35 + .1481\, p_{1,-1}$ $(-.84) \quad (1.62)$	.15	1957-72
(18)	$h_1 = 3.96 + .1175\, g_{1,-1} + .7669\, f_{1,-1}$ $(.09) \quad (2.98) \quad (6.87)$	.74	1949-72
(19)	$h_2 = 50.3 + .0173\, g_{2,-1} + .2900\, f_{2,-1}$ $(1.97) \quad (.87) \quad (1.31)$	.19	1954-72
(20)	$g_1 - g_{1,-1} = 110.2 - 1.360\, p_1 + 2.150\, \pi_1 + 1.733\, d_1 - .5138\, h_{1,-1}$ $(.53) \quad (-1.67) \quad (2.76) \quad (.69) \quad (-2.23)$	.44	1949-72
(21)	$g_2 - g_{2,-1} = -330.0 - 3.760\, p_2 + 10.58\, \pi_2 + .5094\, d_2 - 1.913\, h_{2,-1}$ $(-.72) \quad (-.62) \quad (2.40) \quad (.11) \quad (-1.60)$	.43	1954-72

concessional exports, and (20) and (21) are used as the control equations for government inventories. The statistical implications of these reaction functions over a ten year period starting in 1975-76 are included at the bottom of Table 3. By reducing supply, they maintain prices above the free-market level with small inventories and concessional exports. In fact, expected wheat supply remains at the low level of 1854 m.bu. at the end of the 10 year period in spite of the technological advance assumed in the supply function. It is noteworthy that historical policies result in standard deviations of prices and inventories that are even larger than those produced by the free market.[15] Their expected surplus, however, is about the same as that produced by policies 5 and 6 when disposals are treated as supply reductions.

Stochastic Dynamic Behavior of Prices

Figure 2 exhibits the power spectra of prices produced by the three market regimes considered in this paper. The spectrum of wheat price shows that while the unregulated market produces oscillations (high power at high frequencies), historical regulation magnifies long cycles (high power at low frequencies). On the other hand, optimal stabilization reduces the power spectrum over all the frequency domain. Policy 6 reduces the frequency of oscillations to the level attained by postwar regulation while maintaining the more stable performance of the unregulated market over the long run.

The spectrum of feed grain prices exhibits more power at all frequencies under observed regulation than in the unregulated market, which suggests that the lesser volatility of these prices allowed policymakers to trade stability for other goals. Policy 6 produces almost the same feed grain price spectrum as the unregulated market. That is, the stabilization effort under optimal control deals with the fluctuation of wheat prices, rather than with the smaller fluctuations of feed grain prices.[16]

Policy 7, which takes into account current supply and export fluctuations, reduces the power spectrum of wheat and feed grain prices over all the frequency domain. Again, most of the improvement is attained by stabilizing wheat prices.

[15]This is so in spite of the fact that the variances of the estimated functions are ignored here. In particular, government inventories, not being under active management, were subject to considerable random variation during the postwar period.

[16]Further stabilization of feed grain prices would require increasing the weight assigned to its MSD, or decreasing the weights assigned to the MSD of the instruments. The stabilization of feed grain and livestock markets is studied in Arzac and Wilkinson (1979b).

Concluding Remarks

This paper has shown how methods of stochastic control and dynamic analysis can be applied to perform comprehensive policy analyses of commodity markets. A number of substantive results were derived for the case of the U.S. grain market. The difference in the aggregate domestic consumer and producer surplus produced by the unregulated market and surplus maximizing policies is small and probably within the margin of error of this study. Moreover, domestic surplus stayed at the same level over a wide range of policies, suggesting that other goals may be pursued without reducing surplus. This is an important implication in view of the fact that the unregulated market version of the model results in declining and volatile grain prices and farm income. In fact, it was verified that policies directed to stabilizing prices and maintaining farm income do not reduce domestic surplus. Furthermore, it was found that price stabilization and farm income support can be attained by mixtures of inventory and grain disposal management but that inventory management alone results in an excessive accumulation of stocks. A characterization of historical policies toward the U.S. grain market was found to have destabilizing effects on the market model. Finally, the power spectra of grain prices under optimal stabilization are significantly below those produced by historical policies and by the unregulated market.

Some of the limitations of the present study should be pointed out. An obvious one is the rudimentary nature of the model utilized. In particular, the supply response of risk averse farmers who face price instability and government regulation may not be adequately modelled by the usual specifications. Furthermore, private inventory and grain supply depend on expectations about future spot prices, which are in turn a function of government policy. Albeit crudely, our model takes this dependency into account. However, in view of Lucas' observations, it appears desirable to check the policy implications of the present paper by estimating and controlling the model under the

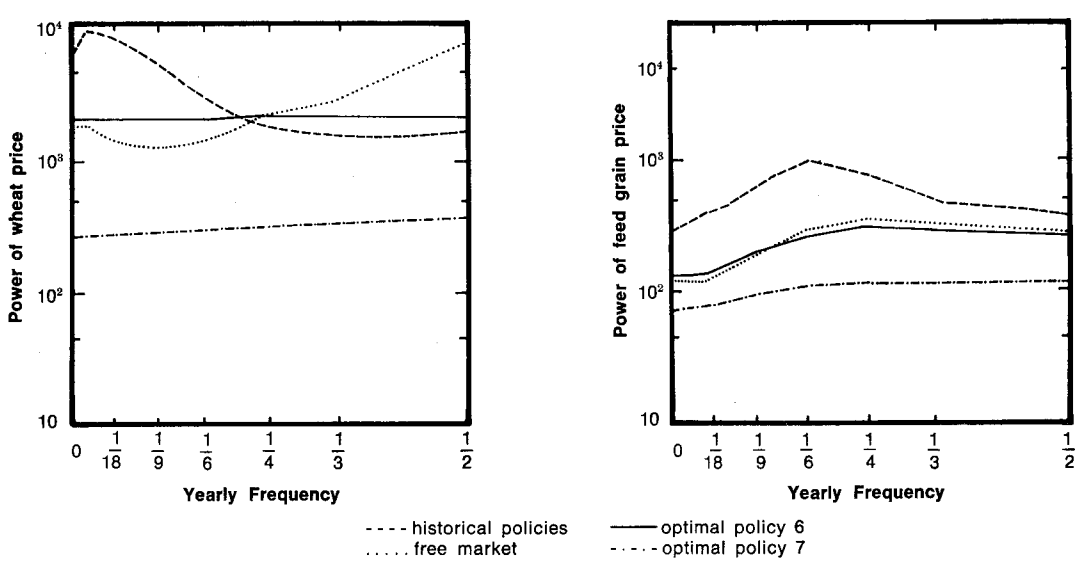

Figure 2. Power spectra of grain prices in free and regulated markets.

hypothesis that expectations are formed rationally. It should be noted that, contrary to Kydland and Prescott's claim, optimal control theory is still appropriate when current decisions of economic agents depend on expectations of future policy actions. This point has been clearly demonstrated by Chow (1978). Finally, the present paper has not evaluated the distributional effects of price stabilization. It seems that such an evaluation should be made using a more general nonlinear specification of the market model. While the desirability of overall price stabilization seems to hold rather generally [Samuelson], the distribution of welfare gains has been shown to be highly sensitive to the form of the supply and demand functions and the nature of the stochastic disturbances [Turnovsky (1976), (1978)].

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