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Introduction

One of the most important objectives in a grain storage program is to achieve the price stabilization. Consequently, a fundamental question associated with a storage program is who benefits and who loses from the price stabilization. Many studies have been published to answer this question. Waugh (13) took his proposition in early 1940 that consumers are better off from the price instabilization than the prices stabilized at their mean if the source of price instability is stochastic fluctuations in supply. Some years later, Oi (11) demonstrated that producers facing random price due to stochastic shift in demand are worse off from having prices stabilized at their mean. These two studies considered the welfare of one group only and ignored effects of price stabilization on the other group. Massell (10) put consumers and producers together in a single framework under the assumption that demand and supply curves are linear with additive stochastic disturbances. According to his study, welfare gains to each group are indeterminate and depend upon the relative size of variances and the slope of the demand and supply curves. A limitation of this study is the assumption of linear supply and demand curves with additive stochastic disturbances which are not always true in application.

Turnovsky (12) extended Massell's analysis to the case where demand and supply curves are non-linear with multiplicative disturbances. He found that the benefits of price stabilization do not depend upon the source of price instability but upon the shapes of the deterministic components of the demand and supply curves. However, all these theoretical studies have serious limitations. Most of the theoretical works consider only the two polar of no storage versus sufficient storage to completely stabilize price. Storage costs are assumed to be zero and discounting is not used.

Our earlier study (3) "Optimal Stochastic Control of U.S. Wheat Stocks and Exports" shows the empirical measures of benefit distribution between consumers and producers under alternative specifications of demand and supply functions in the U.S. wheat industry. This study indicates that U.S. wheat producers get most benefits from a storage program, while both Domestic and Foreign consumers experience losses. Although the curvature of demand and supply equations and the structure of the disturbances have an impact on the benefits of the various groups, the qualitative results of who benefits and who loses were not changed by any of the alternative specifications considered.

A question of who benefits and loses from the price stabilization still remains. The purpose of this study is to evaluate alternative storage policies such as welfare and price stability in terms of changes in social welfare between producers and consumers.

Methodology

The mathematical model is that of stochastic dynamic programming based on a Markovian sequential decision making process with a finite number of states. The only decision variable is quantity of wheat exported with indirect controls of year to year carryover stocks. Otherwise, this study assumes free market condition in the wheat industry with no government controls on production.

The model has two state variables which are wheat stocks and wheat price at the Gulf Ports, and one decision variable which is wheat exports. Since this study assumes that the export decision should be made immediately after harvest each year, the measure of stocks used as a state variable is the sum of wheat carried over from the previous crop year and wheat production in the current season. The model makes export decisions a function of two state variables to maximize the present values of expected returns over the planning horizon.

The recurson formula of the dynamic progamming is mathematically expressed as follows

$$(1) \quad V^{n}_{im} = \max \{q^{k}_{im} + \beta \sum_{i=1}^{15} \sum_{m=1}^{10} P^{k}_{imjp} V^{n-1}_{jp}\}$$

where q^{k}_{im} is the expected return associated with the ith stock and mth price for the kth decision; β is the discount rate; P^{k}_{imjp} is the joint transition probability for the kth decision alternative of moving from ith stock mth price to jth stock and pth price and V^{n-1}_{jp} is the optimal present value of the expected net returns from the n-1 state decision process when the initial state is the jth stock and pth price.

The joint transition probability and expected returns used in the dynamic programming are calculated from the estimated supply and demand equations of the U.S. wheat industry. The estimated demand equations including demand for food, demand for animal feeding and demand for seed have a simple linear relationship with market price, while the estimated acreage and yield response equations have a complex structure with lagged prices and dependent variables. Since the dynamic model uses season average wheat price at the Gulf Ports as one of the state variables, this study estimates short-run and long-run supply equations containing only one lagged price for time t, t+1, t+2, and t+3 from the estimated supply equations by utilizing all possible information on lagged price and dependent variables. These short-run and long-run supply equations are used with the estimated demand equations to calculate the corresponding transition probabilities and expected returns. The long-run information is used in the dynamic model to get asymptotic decision rules. The asymptotic decision rules are improved by incorporating short-run information through a proximate solution method suggested by Arrow (1).

The structure of this model is the same as the earlier study. The only differences of this study from the earlier study are criterion function and structure of the demand equation for U.S. wheat exports. In the earlier study, we used Box-Jenkins type time series analysis on the market price at the Gulf Ports to estimate a mean price associated with each level of price state variable in the model. Then the influence of U.S. exports on World price was taken into account as follow:

$$P_t = \alpha_0 P_{t-1}^{\alpha_1} + \beta\,(\bar{E} - E)$$

where P_t is season average wheat price at the Gulf Ports, E is quantity of U.S. exports and $\bar{E}$ is mean export of U.S. wheat. However, we became a little skeptical of the autoregressive price relationship in the foreign demand; the reason being that exports in a dynamic optimization model can be controlled over time to manipulate this lagged price which would be assumed to be exogeneous. The sensitivity analysis in our earlier study suggested a considerably higher risk associated with assuming the autoregressive as opposed to the static equation.

The export demand equation for U.S. wheat used in this study is static equation as follows:

$$P_t = P_0 + \beta\,(E - \bar{E})$$

The value of β was calculated by introducing the price elasticity of demand for U.S. wheat exports. This elasticity was estimated by aggregating World regional demand elasticities estimated by Konandreas. The elasticity used in this study was -2.5 which is quite close to that estimated directly by

Konandreas and Schmitz (8).

The criterion function used in this study is to stabilize season average wheat prices at the Gulf Ports at their mean price subject to the various capacities of U.S. wheat storage. Consequently, the price stability criterion is expressed as the expected variance of market price associated with each level of the price state variable. The domestic and World welfare criteria are considered as alternative criteria in this study. The domestic criterion is the sum of consumers' surplus and producers' surplus minus storage cost, while the World criterian contains consumers' surplus associated with export demand equation in addition. The method of calculating surplus values and transition probabilities are detailed in (3).

Results

The results obtained from the dynamic model are divided into two groups as follows: long-run and short-run decision rules. The long-run optimal decision rules are obtained from equation 1 directly over 20 years planning horizon by utilizing the information associated with the long-run demand and supply equations. The short-run decision rules are obtained by improving the long-run results by utilizing the information associated with the short-run demand and supply equations. Finally computations are completed to correspond to a desired decision on wheat exports in the fall of 1976 since the starting point of the planning horizon is the fall of 1976.

The 1976 and long-run decision rules are quite different which indicates the importance of the extra information used in developing the 1976 decision rules. The expected net gains obtained by improving the long-run results are about 150 million dollars under both World and Domestic criteria.

U.S. Wheat Export and Storage Policy

The situation with respect to the two state variables in the fall of 1976 was wheat stock equal to 2800 million bushels and season average price at the Gulf port of $4.03. The optimal exports indicated by the results were 1050, 1250 and 1450 million bushels for the price stability, domestic and World criteria, respectively. The export levels in the domestic and world criteria are much larger than the actual export of 950 million bushels in 1977 and therefore, derive the world wheat price lower than what was experienced for the crop year.

Table 1 shows expected stocks, prices and exports which were calculated from the marginal probabilities associated with the optimal decision rules under alternative criteria over time. Expected prices are much higher and expected stocks are larger in the price stability criterion than in both domestic and world criteria. The reason is the price stability criterion restricts wheat exports as much as possible to keep the world wheat price close to the mean price, and consequently, cummulates large wheat stocks. The price stability criterion would have an expected wheat stock of 3,680 million bushels to keep the world wheat price at $2.89 (1976 dollar) which is much higher than prices in both domestic and world criteria in 1977. The expected wheat stocks in the domestic and world criteria are 3496 and 3296 million bushels, respectively, in 1977. There is a strong tendency for having higher prices, lower stocks and lower exports in all three criteria in later years. The long-run expected wheat price is $3.22 (1976 dollar) for all criteria. The expected wheat stocks are 2600, 2201 and 2034 million bushels in the price stability, domestic and world criteria, respectively in the long-run. There is not much difference in the long-run expected exports between criteria; 840 million bushels in the Domestic and World criteria and 830 million in the price stability criterion.

The choice of U.S. wheat exports under a long-run decision rule is closely

Table 1

Expected Wheat Stocks, Prices and Exports in Alternative Criteria Over Time*

	1977	1978	1979	1980	n ∞
Prices in	2.89	2.73	2.71	2.83	3.22
1976	2.58	2.65	2.63	2.83	3.22
dollars	2.28	2.60	2.47	2.84	3.22
Stocks in	3,679.6	3,689.9	3,615.9	3,380.8	2,600.0
million	3,495.7	3,481.5	3,383.2	3,140.3	2,201.1
bushels	3,295.7	3,201.9	2,995.6	2,727.5	2,033.5
Exports in	1,150.2	1,177.8	1,143.9	1,073.5	830.0
million	1,229.8	1,187.1	1,198.4	1,041.1	839.6
bushels	1,342.7	1,242.5	1,243.1	1,069.9	840.0

*Note: Top, middle and bottom rows in each group indicate expected values in price stability, domestic, and world criteria, respectively.

related to the quantity of wheat stocks on hand and season average wheat price. Thus, this study presents the long-run optimal decision rules as a function of wheat stocks and season average wheat price at the Gulf Ports. Based on long-run expected wheat stocks and prices, the long-run optimal decision rules are to export 850 million bushels in the price stability and domestic criteria, and 1050 million bushels in the World criterion.

Price Stability and Benefit Distribution

Price stability is highly correlated with storage capacity. Table 2 shows the percentage increases in the stability of wheat price under alternative criteria and the various storage capacities. The stability of wheat price increases 28 percent under the minimum variance criterion, 21 percent under the World criterion and 26 percent under the domestic criterion with an increase in the wheat storage capacity from 1000 million bushels to 2000 million bushels. Price stability remains the same with larger storage capacities beyond 2,000 million bushels in both the domestic and world criteria, while the minimum variance criterion increases the stability of the market price further. In contrast, the expected social benefit decreases under the price stability criterion and increases under the domestic and world criteria with larger levels of U.S. wheat storage capacity. The social benefits to domestic producers

Table 2

Percentage Increase in Price Stability
with Alternative Criteria Under the Various Storage Capacities

Alternative	Wheat Storage Capacities in million bushels			
Criterion	1000	2000	2600	3000
Price Stability	0	28%	33%	38%
World	0	21%	21%	21%
Domestic	0	26%	26%	26%

increase, while those to the domestic and foreign consumers decrease with an increase in the storage capacity regardless of criteria considered. This indicates that a storage program in general gives most benefits to domestic producers only and leaves the domestic and foreign consumer worse off. The latter apparently losing the most. Increases in the benefits to the domestic producers are larger in the price stability criterion than in other criteria when storage capacities are increased. This also indicates that only domestic producers gain from price stabilization, while domestic and foreign consumers experience losses.

Again, the reduction in the benefits to the foreign consumers is much larger than any other group from the price stabilization.

The net values of the benefits under the price stability criterion are smaller than those under the domestic and world criteria for each storage capacity. The differences in the benefits between the price stability and the domestic or world criteria can be interpreted as a social value which must be given up to increase the stability of the market price in

Table 3
Expected Net Social Benefits in the
Various Storage Capacity Under Alternative Criteria*

Storage Capacity	Domestic Producer	Domestic Consumer	Foreign Consumer	Variable Cost	Total Benefits Domestic	World
	688	26,960	1,327	14	27,634	28,961
1,000	688	26,960	1,327	14	27,634	
	688	26,960	1,327	14		28,961
	1,158	26,928	1,154	45	28,040	29,193
2,000	1,149	26,938	1,197	38	28,049	
	1,114	26,946	1,230	31		29,260
	1,238	26,809	981	92	27,953	28,934
3,000	1,199	26,919	1,181	50	28,088	
	1,138	26,938	1,237	37		29,276

*Note: Top, middle and bottom rows in each group indicate the expected social benefits under price stability, domestic and world criteria, respectively.

each storage capacity. For example, the price stability criterion achieves a price stability improvement of 2 percent but at the same time decreases the expected social benefit by more than 9 million dollars over the domestic model with a fixed storage capacity of 2000 million bushels. More social benefits should be given up to get the same percentage increase in price stability in the world model because of a large reduction in the foreign consumers' benefit.

However, this is an extreme comparison between two fundamental criteria. A generalized risk criterion which combines the expected benefits and the price stability criterion together in a single framework shows a combination of two fundamental storage policies; the maximum social benefit and the price stability. This combined policy varies with the social preferance between the social benefit and price stability. The various combinations between these two stroage policies can be expressed as an efficiency frontier line analogous to the mean/variance efficiency frontier of micro economic theory of the firm. This efficiency frontier has a steep downward slope and is concave from the origin in both the domestic and world criteria. The frontier curve for the world criterion is much steeper than that for the domestic criterion. The nature of the frontier curve indicates that opportunity cost associated with the price stability criterion is much larger than that associated with the social benefit criteria. Also, the steep concavity of the frontier curve indicates that increasing cost scale associated with the price stability criterion is much larger than that with the social benefit criterion.

Conclusion

Under the situation with respect to wheat price and stocks in the fall 1976, the optimal decisions were to export 1050 million, 1250 million and 1450 million bushels in the price stability, domestic and world criteria. The export levels in the domestic and would criteria are much larger than actual export of 950 million bushels in 1977 and drive the world wheat price lower than what was experienced for the crop year. Expected wheat prices were \$2.89, \$2.58 and \$2.28 per bushel in the 1976 dollar in the price stability, domestic and world criteria. However, U.S. wheat market will be stabilized at expected wheat price of \$3.22 in the 1976 dollar, expected wheat stocks ranging from 2600 million bushels in price stability criterion to 2000 million bushels in world criterion and expected wheat stock of 840 million bushels.

Domestic producers get most benefits from the price stabilization which obtained from the price stability criterion, while domestic and foreign consumers experience losses. However, the total benefit under the price stability criterion is smaller than that under both domestic and world welfare criteria. This indicates that a commodity storage program faces a trade-off between two fundamental storage policies; price stability and social welfare. These two storage policies can be combined together in a single storage program, and can be expressed as an efficiency frontier line analogous to the mean/variance efficiency frontier of micro economic theory of the firm. The nature of this frontier curve indicates that opportunity cost associated with price stability is much larger than that associated with social benefits.

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