The Dynamics of Supply, Demand and Price for Wheat Programs under Rational Expectations

by

Theresa Y. Sun and Mario J. Miranda

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There has always been interest from theoretical and empirical perspectives in examining the effects of government price programs in commodity market. The purposes of these various programs are either to support producer prices and increase producer income, or to reduce price and/or income fluctuations. Different approaches have been adopted to analyze these income protection and price stabilization policies. Most approaches, however, have been in the context of static models (Blandford and Lee). Recently, there have been efforts applying stochastic dynamic programming techniques to commodity markets, but only a few of these studies include government storage programs (Gardner, Gordon and Plato, Wright and Williams). This study uses the rational expectations model developed by Miranda and Helmberger to examine the dynamic equilibrium processes of price and quantities under both competitive storage and price-intervention markets (Miranda and Helmberger). The computational rational expectations model is capable of dynamically adjusting private storage and production activities to government price support and price band policies. Both price support and price band policies involve public storage for later resale. In the price support policy, stocks are accumulated if market price is below the support price, and released if market price is equal to or above the support price. In the price band policy, the storage release price is higher than the support or price floor.

In examining the dynamic wheat market process, we concentrate on three different aspects in these competitive storage and price-intervention markets: the equilibrium trajectories of quantities and prices, the time path of revenue and its instability relative to price, and the gains and losses in welfare for the different market groups. Hence, the analysis systematically explores the market equilibrium behavior and government intervention effects in both the dynamic transition and long-run equilibrium states. The empirical results indicate:

- Intertemporal patterns of market variables may vary in both sign and magnitude according to the initial supply in the beginning equilibrium process being larger or smaller than its competitive steady-state. Price constrained market may change the level and rate of adjustment, but not the direction of these time paths.
- Price support reduces price instability but increases revenue instability. Compared to the price support policy, price band increases price instability but decreases revenue instability. Both price and revenue instability change over time.
- Price policy may increase short-run revenue or producer welfare, but over longer period, economic gain may be reduced.

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Of course, all results are subject to the institutional and technical relationships underlying the model. In the following, we provide a general description of the market model, and the policy and econometric parameters chosen for the simulation. Next, the different aspects of simulation results and their implications under different policies. The paper concludes with a brief summary of the implications for policy and suggestions for future research.

The Market Model

The computational rational expectations model extends a stochastic competitive storage model with rational expectations to allow for public storage decisions. Consequently, the model is capable of generating both competitive and policy restrained storage markets. The behavioral relations consist of stochastic supply, demand, an arbitrage condition, and a government storage program. Relationships between the variables and across time are characterized by nonlinearities and inequalities. To render the problem manageable, the model assumes that producers and arbitragers are risk neutral, and harvest is subject to probability distributions that are agreed upon by all producers and storers. This assumption enables producers and storers to formulate common price expectations consistent with the distribution of prices generated by market process--i.e., rational price expectations. In addition, the functions and parameters of the model are time stationary.

Market Relations: Because of the assumptions of rational expectations, a complete solution to the model involves future expected paths of prices and quantities conditioned on current and past economic variables. Specifically, there are initial supplies of the commodity (wheat) held by private and government sectors. The initial supply held by government is the past period stock y_{t-1}. Private market initial supply s_t' consists of past private stock x_{t-1}, and a new production that is the outcome of acreage planted the preceding year a_{t-1} times a random per acre yield $\tilde{w}_t$:

(1) $s_t' = a_{t-1} * \tilde{w}_t + x_{t-1}$

The current economic relations include current market supply, current government storage, consumption demand, storage arbitrage condition, acreage planted and expected price functions. Of course, all these relations may be conditioned upon the nature of government program. For equilibrium, the initial private supply plus the past period government stock equals the total sum of current consumption c_t, private carryover x_t and current government stock y_t:

(2) $s_t' + y_{t-1} = c_t + x_t + y_t$

Thus current supply s_t equals initial supplies held by private and government sectors minus current government stock.

(3) $s_t = s_t' + y_{t-1} - y_t$

Consumption demand c_t, depends on the difference between current supply s_t, and the amount stored as private carryover x_t.

(4) $c_t = s_t - x_t$

The inverse demand function is a strictly downward sloping function of the consumption level:

(5) $p_t = \pi(c_t)$

The arbitrage condition specifies that the amount stored would not be in equilibrium unless competition among expected-profit-maximizing arbitragers eliminates profit opportunities to the point where discounted expected price is equal to or smaller than the current price including storage cost. Let the discount factor δ be less than one and the cost of storage k be positive. Mathematically, the optimal storage level must satisfy the following intertemporal arbitrage condition,

(6) $x_t \geq 0, \quad p_t + k - \delta EP_{t+1} \geq 0$

with complementary slackness. Complementary slackness means that at least one of the two inequalities must hold with equality.

The acreage planted by producers depends on the rational price expectation of next year's price at harvest time,

(7) $a_t = \alpha(E_t P_{t+1})$

A rational price expectation function that is unknown a priori is present in both the acreage production, (6), and arbitrage condition, (5). The function is determined through stochastic dynamic programming. The general form of the price expectations function is:

(8) $E_t P_{t+1} = f(x_t, y_t, a_t)$

Government Program: Government held storage depends on how the support price or price band policy links prices to government purchases or sales. Let the support price be $\overline{p}_s$, the release price $\overline{p}_r$, the net government purchase at year t be $g_t = y_t - y_t$. Four sets of mutually exclusive price and net government purchase relations are available:

A. If the market price falls below the support level, the government will acquire the commodity at the support price, causing price to rise to the support level; $p_t = \overline{p}_s$ and $g_t > 0$.
B. If the market price rises above release price, the government releases stocks up to its total stock; $p_t > \overline{p}_r$ and $g_t = -y_{t-1}$.
C. If the market price is equal to release price, government sale is in between 0 and the amount of the original stock y_{t-1}.
D If the market price is in between the support and release price, government will not engage in open market purchase or sales.

Model Application

To employ the above model in simulating the wheat market, we parameterize the model using least squares estimates of acreage supply, and domestic and export demand equations estimated from annual data for the years

1960-87. Domestic and export demand elasticities are -.42 and -.54 respectively. Acreage elasticity is .31. For the intertemporal arbitrage condition, annual real interest rate is set at 4 percent, and storage cost is $0.36 per bushel per year. The random yields $\tilde{w}_t$ were assumed to be independently and identically distributed following a standardized log-normal distribution with zero mean and standard deviation of .067.

In the market model, the random sequence of supplies at each period follow a simple Markovian scheme (Miranda, 1985). The distribution of these supplies is derived by simulating the stochastic model dynamically. Given the steady-state distribution of supply, the expected values of quantities and price in the model can be derived.

Since wheat planted acreage has averaged about 61.35 million acres recently, we choose 56 million and 90 million acres respectively to represent a small and a large wheat acreage planted. With average yield at 38.1 bushels per acre, these acreages translate into corresponding small, average, and large initial supplies of 2.13, 2.34 and 3.25 billion bushels respectively. The small and large supplies are used as initial conditions for simulating the competitive market. Price support policy usually has a price-raising rationale, thus we use the average and large initial supply conditions to simulate the equilibrium process for the price support markets. Five different levels of support price are used for each initial supply. The support prices for large initial supply ranges from $2.80 to $3.60 per bushel at $0.20 intervals, those for small initial supply range from $3.0 to $3.80 per bushel at $0.20 intervals.

The price band policy can be compared with a price support policy by setting support price as a fixed price floor. For the comparison of equilibrium processes between price support and price band markets, we use a large initial supply (3.43 billion bushels) composed of 56 million planted acreage, 10 million bushels of carrying from private storage and 0.3 million bushels of government stock. Four sets of price bands each with increasing width are examined. The floor prices of the four sets of bands increases by 20 cents per bushel from $2.80 to $3.40 per bushel. Within each set of bands, the release price also increases successively by 20 cents per bushel for six levels.

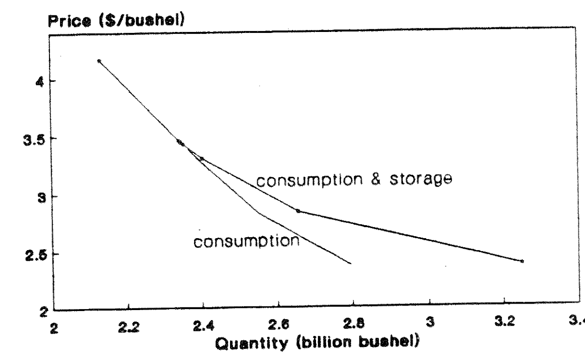
Simulation Results and Implications

The simulation involved generating 10 years of equilibrium quantities and prices and calculating means and standard deviations by year to explore the transition from initial conditions toward a stochastic steady-state. Simulated results are examined in terms of: (1) the characteristics of price-quantity movements in the competitive and policy restricted markets, (2) the price instability and price policy, (3) the revenue and revenue instability issue, (4) the welfare redistribution changes.

Price-Quantity Movements in the Competitive Market

The means and standard deviations (or variances) of price and quantity streams in the competitive market move in different directions according to the supply being larger or smaller than its steady-state mean in the beginnin equilibrium process. Specifically, if the initial supply is smaller than its steady-state average, expected equilibrium price would be high in the beginning, and later decrease towards its steady-state. Acreage, responding to the expected price, would also increase at first and then decrease from above its competitive steady-state. Meanwhile, expected consumption and storage would increase from their lower then long-run equilibrium values. Conversely, if the initial supply is larger than its steady-state mean, expected equilibrium price and acreage would increase from low starting values, and storage and consumption decrease from high starting values toward their steady-states. Figure 1 presents the expected trajectories of consumption and total market demand (consumption plus storage) relative to price for different initial supplies at the competitive market.

Figure 1. Short Run Demand Function Competitive Market



Steady-state price=$3.45 per bushel
Steady-state supply=2.34 billion bushels

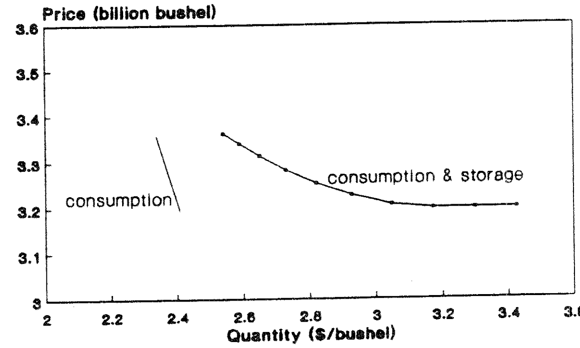
The two patterns of short-run rational equilibrium values represent two series of adjustments by consumers, producers and marketing agents at sequential time periods. Shown in the lower part of figure 1, a large initial supply brings a short-run mean market price of $2.37 per bushel. This price is lower than the long-run market average of $3.45 per bushel. Private storage increases and the wheat price anticipated in the following period is as low as $2.84 per bushel. With rational production response, producers reduces wheat acreage planted to 57.75 million acres. Although production in the second period is lower than that of the first period, the carryover from the previous period still makes total supply to be more than the steady-state supply. However, since supply is lower than the previous period, expected price and acreage increase accordingly. As long as the increased production plus previous period storage constitute a supply that is more than the steady-state but less than its previous period, the process of increasing price, decreasing consumption and storage would continue, until the industry reaches the stochastic steady-state.

If the market supply is sufficiently small, (the upper half of Figure 1), the high level of market price ($4.16 per bushel) will reduce consumption and suppress storage activity. But at the same time, high expected price induces larger than steady-state acreage planted. Consequently, consumption increases and storage develop. In turn, expected price declines. If both expected price and acreage is still higher than their steady-states, the downward process will continue until it reaches the point where the change in total supply just equal to the change in total demand.

Price-Quantity Movements in Policy Restricted Markets

Although a government price intervention will not change the direction, it will change the level, the speed of adjustment and even the stochastic steady-state in the market equilibrium process. To be more specific, a support price (or price band) policy will always increase the current period price expectation. However, changes in future expected prices may be smaller in the policy-oriented market. If the support level is close to or above the competitive steady-state, long-run equilibrium price may also change. Figures 2 and 3 present, respectively, the expected equilibrium trajectories of consumption, total demand and price under the support price of $3.2 per bushel with large initial supply, and the support price of $3.6 per bushel with average initial supply. In figure 2, the beginning-period equilibrium price is raised to the support level of $3.2 per bushel. Since the range of price change for the equilibrium process is only $0.16 per bushel, as compared to $1.08 per bushel for the competitive market, it implies a smaller rate of price change in the support market. In figure 3, long-run equilibrium price is raised to $3.6 per bushel with increasing storage.

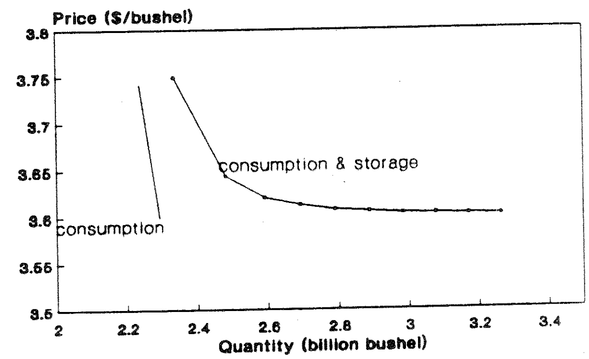
Figure 2. Short Run Demand Function
Price Support Market
(High Initial Supply)



Support price=$3.2 per bushel

The different equilibrium adjustment rates are the result of interactions of storage, price expectations and production in different time periods. In the competitive storage market, storage and expected price forge a connection between current and future supply. Price supports will not only increase current price and storage, but also current expected price and acreage planted. Increased acreage increases next period's supply. Increased storage will do the same in the case of pure support price policy, where the release price equals the support price. If the release price is not equal to the support price, supply will be temporarily restrained until market price reaches release price. The intensity of the link between current and future supply can be characterized by the relative levels of the support, release and competitive steady-state prices, and the amount of initial supply in the market. With high initial supply, the higher the pure price support, the higher the amount of initial government storage, and the lower the rate of price increase in the successive period. At the support level close to the competitive steady-state (figure 2), the rate of increase in the expected price is so low that the long-run equilibrium may be less than that of the competitive steady-state. If the support level is raised above the competitive steady-state, consumption will be depressed to a lower and constant level, and government storage will grow continuously.

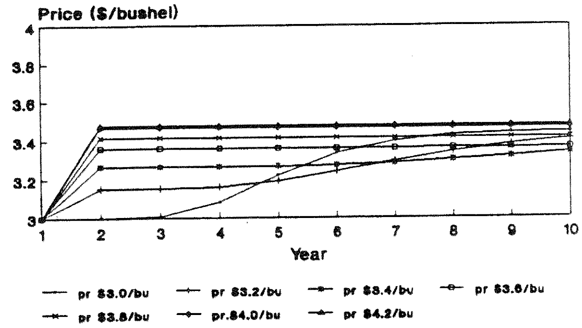
Figure 3. Short Run Demand function
Price Support Market
(Average Initial Supply)



Support price=$3.6 per bushel

Comparing the price band with the price support policy, the higher release price of the former will decrease the chance of releasing government stock to the market in the immediate future. This in turn will reduce the price adjustment rates in the later period. Consequently, price is higher in the initial periods, but slower in approaching the steady-state in the price band market. Figure 4 presents time paths of expected (mean) equilibrium price under widening price band for the price floor of $3.0 per bushel. The time path of release price $3.0 per bushel in this figure is the mean price trajectory of zero price band (or the price support policy). As release price increases, the short-run price level also increases. However, subsequent price change is less in the band policy, with the result that the long-run price level may also be less than that of the support price policy. In addition, the level of price will not increase without limit. At the release where explosive storage begins, price will cease to increase.

Figure 4. Expected Evolutin of Price
Price Band Policy
(Price Floor $3.0 Per Bushel)



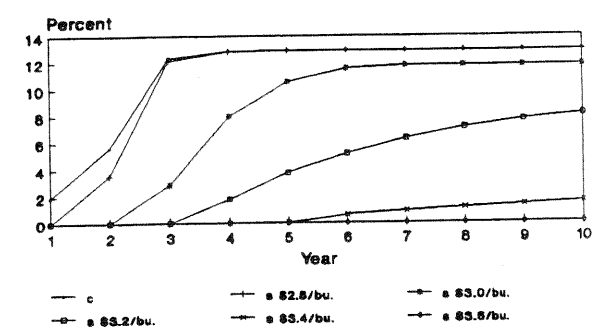
Pr=release price

Price Instability and Price Policy

The purpose of either the price support or price band policy is to increase producer revenue or to reduce price/revenue instability. However, one could not answer the question as to what is the best price scheme for either of these purposes without differentiating between the short- and long-run. The time path of coefficient of variation indicates that price instability decreases over time when initial supply is small and increases over time when initial supply is large in the competitive storage market. A price support policy will not change these time patterns, but will decrease the level of price instability with higher level of support. Figure 5 presents the time paths of percent coefficient of variation in the competitive and price support markets with high initial supply.

The instability of price in the band policy is studied by comparing the instability paths of widening bands with fixed support price as price floor. Figure 6 presents the time paths of percent coefficient of variation for widening price bands with fixed floor price of $3.2 per bushel. From this figure, one may observe that the higher the release price the more price instability in the beginning periods, but less change of it over time. At certain release price, change in price instability may be reduced to zero, and the long-run instability may also be reduced. If the release price is too high, price instability may also reach a limit. In addition, because a higher level of price support may reduce price instability, a price band with

Figure 5. Price Coefficient of Variation
Competitive and Support Markets
(High Initial Supply)

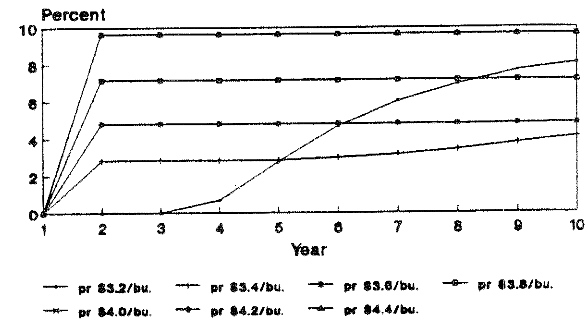


c=competitive, s=support level

the higher level of price floor may also have smaller range of price instability.

In a study of price band policy, Gordon and Plato (1982) observed that the price distribution in a non-storage market is close to normal. It is close to log-normal in a storage market, and bi-modal in a price band market. This information can be used to explain the price instability pattern of this study. It was noted that for a large initial supply, equilibrium price increases over the years. If there is a pure support price or narrow price band, storage will increase and price fluctuation will be reduced in the beginning periods of these price policies. As time goes by and equilibrium price increases toward its steady-state, the support price or narrow price band will become less efficient in reducing or containing prices between the band. Storage will be reduced, and the price distribution becomes less bimodal or log-normal. If the band width widens, it will modify the situation by allowing more private activities within the band, and delays the supply-increasing effect of government storage. As a result, the wider the band, the more price instability in the beginning period, and the slower rate of instability change in latter periods (as compared to the support price policy).

Figure 6. Price Coefficient of Variation
Price Band Policy
(Price Floor $3.2 Per Bushel)



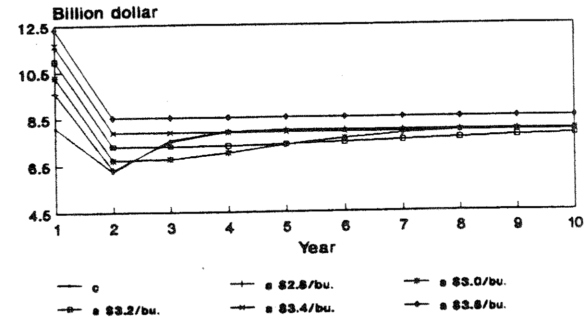
Pr=release price

One of the important issue of price band policy is to design a band that can best contain price fluctuation in the long run. In their study of price band policy for the soybean market, Miranda and Helmberger (1988) noted that combining an average initial market supply with a nonexplosive (storage inducing) price band policy, widening the price band by raising the release price stabilizes market price. Since price instability decreases from initial period towards its steady-state under average initial supply, a wider band will provide higher price expectation and production. As a result, there will be more storage to ward off a low supply situation. If the initial market supply in the equilibrium process is large, like the price band analysis of this study, price instability will increase towards its steady-state. Under such situation, a narrow price band with high price floor will provide more government stock to ward off low supply situations without risking explosive government storage. For instance, for the high-floor price bands of figure 6, the most efficient band is $3.2-$3.4 per bushel, which has the lowest price instability path either in the short-or long-run. A higher release price only increases the level of price instability, and risking explosive storage at a limiting instability path.

Revenue time pattern

The time pattern of revenue is the result of dynamic processes of market price and quantities. In the competitive market with a small initial supply, the revenue time path is decreasing over time because both price and acreage decrease toward their long-run equilibrium. If the initial supply is large, revenue is large in the first period. But then there will also be large storage to decrease revenue in the second period. Eventually, however, revenue will increase towards its long-run equilibrium. A price support policy will always increase the initial level of revenue over that of the competitive market. However, future revenue changes depend upon the rate of change in price and production brought about by the level of price support. Specifically, if the support price is lower than the competitive steady-state, the net result of changes in quantities and price is a larger rate of decline in the immediate future return, and a slower rate of revenue change in latter periods relative to that of the competitive market. If the support price is higher than the competitive steady-state, both short- and long-run revenue will increase at the expanse of unlimited government storage. Figure 7 illustrates the expected revenue time paths for both competitive and support markets with high initial supply.

Figure 7. Expected Evolution of Revenue Competitive and Support Markets (High Initial Supply)



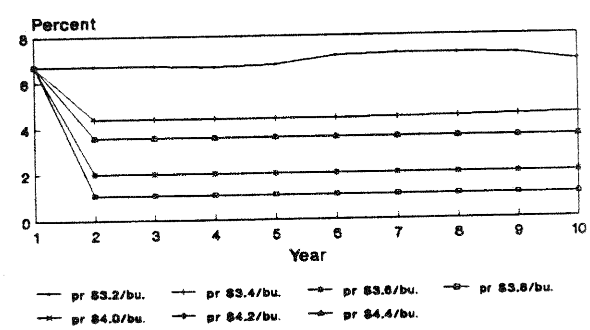
c=competitive, s=support level

The revenue evolution for a price band policy with large initial supply generally moderates the support price pattern by raising its short-run level but slower the rate of convergence towards its long-run equilibrium. In addition, the higher the floor price or wider the band, the less difference between short-and long-run equilibrium.

Revenue Instability

Revenue instability is positively influenced by the variances of price and production, but negatively influenced by the covariance of these variables. In a market with storage activities, storage demand usually dilute the correlation between price and production. If the initial supply is small, storage will not develop in the beginning period, and revenue instability will be closely related to the instability of price and production. If the initial supply is large, there will be storage to reduce the correlation between price and production, thereby increasing revenue instability. A price support policy will reduce current revenue instability when initial supply is small, because support price reduce price instability. But over time storage will increase, and so will revenue instability. If the initial supply is large, a support price will

Figure 8. Revenue Coefficient Variation Price Band Policy (Price Floor $3.2 Per Bushel)

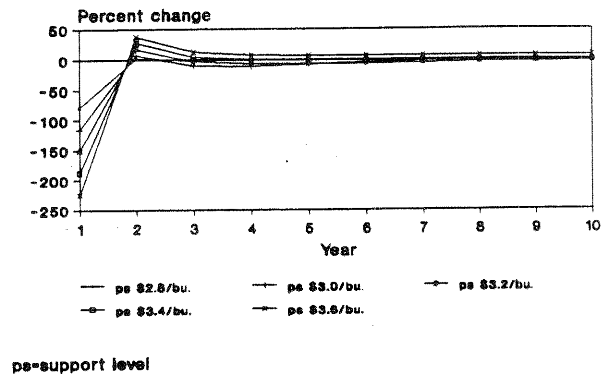


Pr=release price

always increase revenue instability more than that of the competitive market in the short run. But the time path fluctuates more if support price is less than the competitive steady-state.

Because a price band allows more private activities in between the limits of the band, production will be more responsive to price changes than in a price support market. As a result, a price band market will have less revenue instability than the price support market, if the price floor is equal to the support price. Figure 8 presents the revenue instability path for widening price bands with fixed floor price of \$3.2 per bushel. The lowest revenue instability path results from the band of \$3.2-\$3.8 per bushel. Higher release price will induce higher price instability to offset the coordination effect of production and price, thus increasing revenue instability.

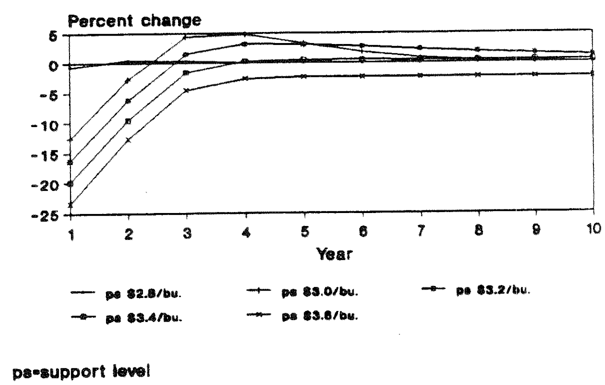
Figure 9a. Expected Producer Gain
Price Support Versus Competitive Market
(High Initial Supply)



Welfare Redistribution

Theoretical analysis of market intervention often centers on the comparative static changes in the welfare of producers, consumers, and society as a whole. Welfare in a dynamic framework concerns discounted expected values of consumer and producer surpluses and deadweight loss at different periods of the dynamic adjustment process.[1] Figures 9a-9c present the time paths of the percentage changes in these expected welfare measures between the price support and competitive markets when initial supply is large. Generally, short-run expected producer gain (or consumer loss) will increase for a price support policy. Long-run expected welfare changes for the different groups will decline, as long as the support level is less than the competitive steady-state price. The rate of decline in the expected gain and loss over time will be smaller, the higher the level of support. For certain level of price support,

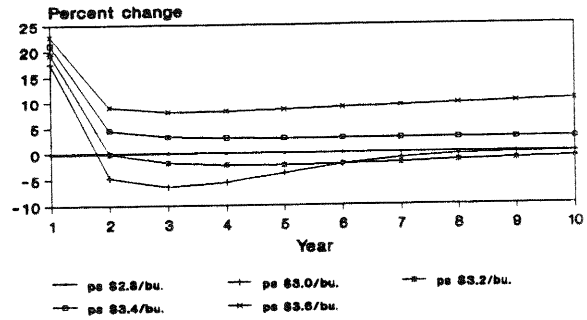
Figure 9b. Expected Consumer Gain
Price Support Versus Competitive Market
(High Initial Supply)



[1]Producer surplus in year t is defined as the difference between realized revenue in year t and discounted cost of planting in year t-1. Consumer surplus in year t is defined as consumer surplus at total market demand net of change in expenditure caused by storage demand. Deadweight loss is defined as the sum of producer and consumer surpluses minus government expenditure in storage program.

it is possible for the expected gain and loss to be lower than their competitive counterparts before they reach their steady-states. These changes in gain and loss over time are the direct consequence of the relative price and quantity movements in the competitive and price support markets. Because of the interperiod connection between production and storage, price in a support market will, over certain periods of time, increase at a slower rate than that of the competitive market. Consequently, changes in gains and losses can be negative at certain periods. In the long-run all changes will approach zero, unless there are explosive storage.

Figure 9c. Expected Deadweight Loss Price Support Versus Competitive Market (High Initial Supply)



ps=support level

A price band policy will have the same pattern of changes in expected gains and losses over that of a support market. As the support price (equals the price floor) increases, expected gain/loss of a band relative to the support policy is likely to reduce. The rate of change in gain and loss will also be reduced over time.

Summary and Concluding Remark

The stochastic dynamic simulation indicates that market equilibrium under rational expectation and arbitrage storage behavior may be characterized as a series of short-run market equilibria and a stochastic steady-state. If in any one period, the market supply is above or below its steady-state average, the values of price and quantities in subsequent periods will, in expectation, regress towards their steady-state means. Specifically, the dynamic market equilibrium convergence to steady-states shows two regimes. Small initial supply is associated with high and falling prices and acreages, but low and rising consumptions and storages. Large initial supply is associated with low and rising prices and acreages, but high and falling consumptions and storages. Large initial supply reduces immediate expected price and acreage planted. It also causes large storage in the first period of the equilibrium process. Since the reduced production usually more than offsets the increased supply through storage, supply is smaller in the following period. This phenomena sets the momentum for the consecutive rise in prices and production in later periods towards the long-run equilibrium. Conversely, small initial supply causes immediate price expectation higher than the steady-state price, and the reversed price and quantity process would ensue.

The dynamic market phenomenon has implications for both theory and empirical application. Theoretical studies of price stabilization usually focus on expected gains/losses for market participants when price is stabilized at its mean value. Unless supply fluctuates close to the market mean, however, price stabilization at the mean could produce explosive storage, thus invalidating the theoretical results. Empirically, public storage policies that raise producer income tend to be successful only in the initial periods. Over time, producer welfare may be worse. The reason, as Wright and Williams pointed out, may lie in the dynamics of market equilibrium adjustment.

The time path of a market variable in the storable commodity market is a result of intertemporal allocation of resource (supply) between current consumption and future consumption (storage). Under a storage price scheme, the interperiods consumption and storage is determined not only by the available initial supply, but also the initial level of expected price the policy generates. To be more specific, the level of a support price (or price band) relative to the competitive steady-state price is important in determining the initial expected price level, and thus the intertemporal pattern of market variables in the policy oriented market.

Comparing a price support with a price band having a price floor equal to the support price, the support price may stabilize price more than the price band, and the band may stabilize revenue more than the support price policy. However, not only price and revenue, but also instability of price and revenue changes over time. A storage price policy aimed at increasing revenue or stabilizing price would do better to consider both the short and long run effects for its success.

The dynamic equilibrium analysis is conditioned on a specific set of demand and acreage response parameters and yield distribution. If demand becomes less elastic, the level of price instability would increase. If acreage is more responsive to expected price, supply would be more flexible. In either case, there would be more burden on the storage adjustment in case of a large random supply, and resulting in different equilibrium process. Since yield distribution is the most important factor to influence random supply and thus expected price, it should be examined in further analysis.

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