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The Effects of Stocks and Price Floor on Price Dynamics and Volatility: An Application to the U.S. Nonfat Dry Milk Market

by

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Abstract: This paper presents an econometric analysis of the effects of price support program and stocks on price dynamics and price volatility. Considering a price support program as a censoring scheme, market prices are specified as a dynamic Tobit model under time varying volatility. The model is applied to the U.S. nonfat dry milk market, based on monthly data for the period of 1970-2000. The econometric results show how the price support program and stocks (both private and public) affect expected price and price volatility. They document the role of stocks in reducing price volatility. The results also show the impacts of market liberalization on price dynamics.

Key Words: storage, price volatility, price dynamics, censored regression, market liberalization

JEL classification: Q0; D4; C5

The Effects of Stocks and Price Floor on Price Dynamics and Volatility:

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1. Introduction

The importance of government intervention in agricultural markets is well documented (e.g., Gardner). It has involved many policy instruments, including import quotas and price floors. Price floors (price support programs) have been a key feature of U.S. agricultural policies since the 1930's. They have been implemented as a means of stabilizing and increasing farm prices, and raising farm income (e.g., Shonkwiler and Maddala; Holt; Holt and Johnson). Price support programs involve government purchase of storable products. For example, in the U.S. dairy sector, support prices are set for butter, nonfat dry milk and American cheese. If the market price falls below the support price, then government purchases take place, thus increasing public stocks. Until the 1990s, U.S. government price support programs were active for major field crops and the dairy sector most of the time. The 1990's have seen a shift in U.S. agricultural policy toward market liberalization. It involved lowering agricultural price support levels for many commodities. The influence of this policy shift on the functioning of agricultural markets remains poorly understood. For example, lowering a support price means reducing the role of government in stock holding and thus increasing the importance of private stocks. The impacts of the changing role of stock holding (e.g., private versus public) need to be better understood. Also, the effects of changes in government price support policy on price dynamics and price volatility are of interest. Given the empirical evidence that most farmers are risk averse (e.g., Lin et al,; Binswanger; Antle, 1987; Saha et al.), understanding the effects of policy change on price uncertainty should provide useful information on the impact of market liberalization.

The objective of this paper is to develop a model of price dynamics under market liberalization, with a focus on the effects of stocks and lowering government support price. Methodologically, our paper innovates in several ways. First, we provide a refined reduced-from investigation of price dynamics in the presence of a price support program. As analyzed by Shonkwiler and Maddala, Holt and Johnson, and others, price support programs tend to increase expected price by censoring the price distribution at the price support level. This generates a model of endogenous switching between a "market regime" (when the market price is higher than the support price) and a "government regime" (when government purchases take place to prevent the price from falling below the support price). Second, by introducing time-varying volatility in the model, this analysis enables us to investigate the changing price volatility and its interaction with the price support program. Third, we investigate the effects of private and public stocks on price volatility. Building on previous work (e.g., Shively), we investigate the role of stocks in reducing price variability, with a focus on possible differences between private and public stocks. The analysis is applied to the U.S. nonfat dry milk market. It provides useful information on the effects of market liberalization on agricultural price, including both price level and price volatility. Some of the important empirical questions to be addressed in this paper are: how did agricultural policy changes affect price dynamics and price volatility?; and how were those effects associated with changes in private versus public stock holding?

The paper is organized as follows. Section 2 develops a dynamic reduced-form model of price determination under a price support program. This involves specifying a dynamic Tobit model of prices that are censored at the price support level under time-varying volatility. In section 3, the model is applied to the U.S. nonfat dry milk market using monthly price and stock data for the period 1970-2000. The econometric results are presented in section 4. They show how the price support program and stock holding affect both expected prices and the volatility of prices. Implications of the empirical results are discussed in section 5. The mean increasing and stabilizing effects of the price support program are documented both in the short run and the long run. We found evidence that stock holding significantly reduces price volatility. The results show how public stock accumulation can contribute to stabilize the market. It is also found that the long term censoring effects of the nonfat dry milk price support program can be significant and large even if the price support is set relatively low.

2. The Model

This section investigates the process of market price determination in the presence of a government price support program. Building on the theory of competitive prices in the presence of stocks, (e.g., Williams and Wright; Deaton and Laroque, 1992, 1996), we first discuss the determinants of price and price volatility. In the absence of stocks, prices can fluctuate over time in response to changes in supply and demand shifters (e.g., weather, consumer income, etc.). If such changes are unanticipated, they contribute to market instability and price uncertainty. However, in the presence of stocks, there is an incentive to reduce inventory when prices are high, and to increase inventory when prices are low. For example, risk neutral storage firm would choose inventory such that the discounted expected price next period is equal to the current price plus storage cost (e.g., Williams and Wright; Deaton and Laroque, 1992, 1996). As a result, one expects storage incentives to affect price dynamics and to reduce price volatility as long as stocks are positive. Then, the market price is determined by the interactions between supply, demand and storage behavior.

Let y_t^* be the market price at time t in the absence of government intervention. Denote the reduced form equation for price determination by

$$y_t^* = f(X_t, \beta) + e_t,$$

where X_t is a vector of explanatory variables including past prices and previous inventory, β is a $(k\times1)$ vector of parameters to be estimated, and e_t is an error term distributed as $N(0, \sigma_t^2)$.

Next, we introduce a government price support program in this market. Let y_t denote the observed market price at time t. The price support program involves a floor price s_t reflecting government policy at time t. When $y_t > s_t$, the price support is inactive. However, if the market price were to fall below s_t, then a government agency intervenes the market and buys (and usually stores) the commodity at a price s_t. This effectively creates a perfectly elastic demand at price s_t, thus preventing any decrease in the market price below s_t. The observed market price y_t is then determined according to the reduced form model:[1]

$$y_t = \max\{y_t^*, s_t\}, \tag{1a}$$

$$y_t^* = f(X_t, \beta) + e_t. \tag{1b}$$

Equations (1a)-(1b) constitute a Tobit or censored regression model (Tobin; Amemiya), where the dependent variable y_t is censored at s_t at time t. Let $D_t = 1$ if $y_t^* > s_t$, and $D_t = 0$ otherwise. From (1a), the latent variable y_t^* is observed only if $D_t = 1$. This corresponds to the "market regime" where the latent price is the market price ($y_t = y_t^*$) and the government price support program is inactive. Alternatively, y_t^* is censored and unobserved if $D_t = 0$. This corresponds to the "government regime" where the price support program determines the market price (with $y_t = s_t$). Equation (1a)-(1b) thus provide a generic model of price determination in the presence of a price support program.

Formally, we introduce dynamic components in the model. Let $X_t = (Y_t, x_t)$, where $Y_t = (y_{t-1}, y_{t-2}, \ldots, y_{t-m})$ is a vector of m lagged market prices, and x_t denotes other explanatory variables (including previous stocks).[2] This gives a convenient and flexible representation of dynamics in the presence of censoring (e.g., Pesaran and Samiei, 1992a, 1992b). In addition, to examine possible changes in price volatility, we allow for a time-varying standard deviation σ_t. Finally, if the price level includes a risk premium, we can capture it by including in x_t the time-varying standard deviation σ_t (e.g., as in the ARCH-M model introduced by Engle et al.).

The implications of the censored model (1a)-(1b) for the distribution of prices are of interest. In particular, the expected value of y_t is (Maddala):

$$E(y_t) = \text{Prob}(D_t = 1) \cdot [f(X_t, \beta) + E(e_t| \, e_t > s_t - f(X_t, \beta))] + \text{Prob}(D_t = 0) \cdot s_t,$$

$$= [1 - \Phi(h_t)] \cdot f(X_t, \beta) + \sigma_t \cdot \phi(h_t) + \Phi(h_t) \cdot s_t, \qquad (2a)$$

where $\phi(\cdot)$ and $\Phi(\cdot)$ are the density and distribution function for the standard normal random variable. The variance of y_t is (see the proof in the Appendix)

$$V(y_t) = \sigma_t^2 \cdot [1 - \Phi(h_t) + h_t \cdot \phi(h_t) + h_t^2 \cdot \Phi(h_t) - [h_t \cdot \Phi(h_t) + \phi(h_t)]^2], \qquad (2b)$$

where $h_t = [s_t - f(X_t, \beta)]/\sigma_t$ and the probability that the censored variable y_t^* is unobserved is denoted by $\text{Prob}(D_t = 0) = \text{Prob}[e_t < s_t - f(X_t, \beta)] = \Phi(h_t)$. Note that expression (2a) is intuitive in that expected price $E(y_t)$ is a weighted average of the support price s_t and of the expected market price conditional on $D_t = 1$ and the weights involve the probability of censoring, $\Phi(h_t)$, e.g., the probability of facing the government regime at time t. Equation (2b) implies that the relative variance $[V(y_t)/ \sigma_t^2]$ equals $[1-\Phi(h_t) + h_t \cdot \phi(h_t) + h_t^2 \cdot \Phi(h_t) - [h_t \cdot \Phi(h_t) + \phi(h_t)]^2]$. This measures the impact of censoring from the price support program on price volatility. For example, in the absence of censoring, the relative variance would equal 1. Alternatively, under censoring (i.e., under the government regime), the relative variance $[V(y_t)/ \sigma_t^2]$ is reduced, indicating how a price support program would decrease price volatility.

Finally, note that, when Y_t involves lagged actual prices ($Y_t = (y_{t-1}, y_{t-2}, \ldots, y_{t-m})$) and error terms e_t are independently distributed, the likelihood function of sample information can be evaluated using simple integrals (Maddala, chapter 6). This means that model (1a)-(1b) can be estimated by standard maximum likelihood estimation. This will allow us to consider more complex dynamics involving a larger number of lags m (compared to alternative specifications that involving lagged latent prices).

3. An Application to the U.S. Nonfat Dry Milk Market.

In this section, we apply our analysis to the dynamics of U.S. nonfat dry milk prices. We investigate the determinants of non-fat dry milk price and its volatility, with a special focus on the role of the government price support program and the effects of private and public stocks . This is done in the context of a heteroscedastistic Tobit model that allows for endogenous regime switching and time varying volatility, where commercial and government stocks affect both the mean and the variance of prices. The empirical analysis is based on monthly data for the period January 1970-July 2000. Monthly nonfat dry milk stock data were obtained from National Agricultural Statistics Service and Agricultural Stabilization and Conservation Service, USDA. This stock series is measured in thousand lbs at the beginning of every month. Monthly nonfat dry milk prices (measured in cents/lb.) are obtained from the U.S. Department of Agriculture (USDA).[3] Government intervention in the nonfat dry milk market has been extensive. During the sample period, the nonfat dry milk price was at the support price level 81.0 percent of the time (as compared to 47.2 percent of the time in the butter market, and 22.2 percent of the time in the American cheese market). Actual nonfat dry milk price and the corresponding support price are shown in Figure 1. Two extreme periods of government involvement can be identified: the early 1980's when the market price was always at the support price; and the mid 1990's when the market price was always above the support price. In the former period, Congress set the support price at a high and constant level, implying the consistent presence of the "government regime." In the latter period, the support price was typically lower than the market price, implying the consistent presence of the "market regime." Other periods exhibited some changes between the market regime (when the price support is inactive) and the government regime (when the price support is active).[4]

Our empirical investigation utilizes the Tobit specification summarized in (1a) and (1b), where $f(\cdot) = \beta_0 + \sum_{j=1}^{m} \beta_j y_{t-j} + x_t \bar{\beta} + e_t$, and $\sigma_t = \exp[\gamma_0 + z_t \bar{\gamma}]$. Note that e_t is distributed $N(0, \sigma_t^2)$ and serially uncorrelated, (β_0, β_j, $\bar{\beta}$, γ_0 and $\bar{\gamma}$) are parameters to be estimated, and z_t is a vector of explanatory variables affecting σ_t. Note that in the case where $\bar{\gamma} \neq 0$, this allows for heteroscedasticity, where z_t affect the volatility of prices.

The following specification was used in our analysis. First, in order to investigate the effects of stocks on the conditional mean and variance of nonfat dry milk price, we introduce lagged nonfat dry milk stocks in x_t and z_t. We allow the stock effects to differ between private stocks and public stocks. As shown in Figure 2, private and public stocks over the sampling period indicate different trends. As expected, government stocks are high (low) when the price support and government purchases are active (inactive) in the market. We include separately lagged commercial stocks (CS_{t-1}) and lagged government stocks (GS_{t-1}) in x_t and z_t. This will provide a framework to investigate formally possible differences between private and public stock effects on price levels and price volatility (see below). From the economics of storage (e.g., Williams and Wright; Deaton and Laroque 1992; 1996), we expect that higher (lower) stocks at time t-1 would tend to reduce (increase) the market price at time t. Also, larger (smaller) stocks are expected to generate lower (higher) price volatility.

Second, we include in x_t a time trend TT and quarterly dummy variables (Q_i equals 1 for the i-th quarter, zero otherwise). The time trend accounts for the effects of long-term trends. The quarterly dummy variables Q_i incorporate seasonality effects in the nonfat dry milk market. Third, in the case where the standard deviation of the error term (σ_t) is time varying, we introduce σ_t in x_t to reflect the situation where a risk premium (captured by the standard deviation of the error term) possibly affects the *expected value* of nonfat dry milk prices (as in ARCH-M models; see Engle et al.).

Next, we explore the issue of possible heteroscedasticity in the form of a time varying σ_t. This would contribute to changing price volatility unrelated to the price support program. Given $\sigma_t = \exp[\gamma_0 + z_t\ \bar{\gamma}]$, we consider introducing in z_t a time trend for the 1990's (T90), as well as lagged nonfat dry milk stock variables.[5] A time trend for the 1990's (T90 equals 1 for 1990, … , 11 for 2000, and zero otherwise) is included to capture possible changes in market instability during the 1990's. Again, both lagged commercial stocks (CS_{t-1}) and lagged government stocks (GS_{t-1}) are included to investigate the possible different effects of stocks (commercial stock versus government stock) on price volatility. As such, our Tobit model specification examines the effects of private and public stocks on both mean price and price volatility in the U.S. nonfat dry market.

This generates the following model of nonfat dry milk price at time t:

$$y_t = \max\{y_t^*, s_t\}, \tag{3a}$$

$$\begin{aligned} y_t^* = {} & \beta_0 + \beta_T\, TT + \beta_{Q1}\, Q_1 + \beta_{Q2}\, Q_2 + \beta_{Q3}\, Q_3 + \Sigma_{k=1}^{m}\ \beta_k\, y_{t-k} \\ & + \beta_{CS}\, CS_{t-1} + \beta_{GS}\, GS_{t-1} + \beta_\sigma\, \sigma_t + e_t, \end{aligned} \tag{3b}$$

$$\sigma_t = \exp[\gamma_0 + \gamma_1\, T90 + \gamma_2\, CS_{t-1} + \gamma_3\, GS_{t-1}], \tag{3c}$$

where y_t^* is the latent nonfat dry milk price at time t, e_t is an error term distributed $N(0, \sigma_t^2)$. In the absence of censoring (where $y_t^* = y_t$), equation (3b) would reduce to a standard autoregressive model of order m, AR(m),with the time trend TT, seasonal dummies (Q_1, Q_2, Q_3), lagged commercial and public stocks (CS_{t-1} and GS_{t-1}) , and σ_t as intercept shifters. The reduced form

(3a)-(3c) represents the determination of nonfat dry milk price in the presence of censoring and conditional heteroscedasticity. This provides the econometric specification used below in the empirical investigation of the impact of price support program and stocks on price dynamics and price volatility in the U.S. nonfat dry milk market.

4. Econometric Results

Following the discussion in sections 2 and 3, we apply model (3a)-(3c) to the U.S. nonfat dry milk market (1970-2000) and estimate the determinants of nonfat dry milk price and price volatility by maximum likelihood. Assuming a correct specification, the maximum likelihood estimation method produces consistent and asymptotically efficient parameter estimates. The order of the AR process (m) in (3b) was determined using the Schwarz criterion (Judge et al. p. 426). This involves choosing m so as to maximize [ln(maximum likelihood) - $K \cdot \ln(T)/2$], where K is the number of parameters and T is the number of observations. The Schwarz criterion selected m = 12. Thus, the analysis below is based on the dynamic Tobit specification (3a)-(3c) with m = 12.

First, we explored whether the stock effects in (3a)-(3c) were the same between private stocks and public stocks. Formally, this was done testing the null hypothesis: $\beta_{CS} = \beta_{GS}$ and $\gamma_2 = \gamma_3$ in (3a)-(3c). Using a likelihood ratio test, the corresponding test statistic was 121.07. Under the null hypothesis, the statistics has an asymptotic chi-square distribution with 2 degrees of freedom. Using a 5 percent significance level, the critical value of the test is 5.99. Therefore, we strongly reject the null hypothesis and concluded that private stock and public stock have different effects. As a result, the analysis presented below allows β_{CS} to differ from β_{GS}, and γ_2 to differ from γ_3.

Next, we investigated whether it is appropriate to introduce heteroscedasticity in the model. This was done by testing the null hypothesis that $\gamma_1 = \gamma_2 = \gamma_3 = 0$ in (3c), under the maintained hypothesis that $\beta_\sigma = 0$ in (3b). Using a likelihood ratio test, the test statistic for this hypothesis was 197.52. Under the null hypothesis of homoscedasticity, the statistics has an asymptotic chi-square distribution with 3 degrees of freedom. Using a 5 percent significance level, the critical value of the test is 7.82. Thus, we strongly reject the null hypothesis of homoscedasticity for nonfat dry milk prices. In other words, we find strong empirical evidence of time varying volatility in nonfat dry prices during the sample period. Note that this changing volatility is unrelated to the effects of the price support program since the censoring effects of the program are already captured in the Tobit specification.

Table 1 reports the parameter estimates of the heteroscedastic dynamic Tobit model (3a)-(3c). First, most of the lagged price effects are statistically significant. This reflects evidence of significant price dynamics in the U.S. non fat dry milk market. Note that β_{t-1}, the coefficient of y_{t-1}, equals 1.505, suggesting an initial overreaction to a recent price change. However, in the absence of censoring,[6] the roots of the estimated AR(12) are all in the unit circle,[7] suggesting that the model is stationary. Both lagged private stocks and lagged public stocks have negative impacts on latent price as expected. Interestingly, the effect of public stock is statistically significant while the effect of private stock is not statistically significant. This may reflect the fact that government purchases are active over 80 percent of the sample period. This provides evidence that public stocks significantly affect U.S. nonfat dry milk prices beyond the direct effects of the price support level. The time trend parameter is positive and statistically significant showing upward trend in price movement. Seasonal dummy variables are all statistically significant. Finally, the standard deviation σ_t is estimated to have a positive but non-significant effect on the latent price. This suggests that, while increased volatility may contribute to a higher risk premium, such an influence is not statistically meaningful.

Consistent with the previous heteroscedasticity test result, the estimated parameters of the standard deviation equation are all highly significant. The coefficient γ_1 for the time trend variable for the 1990's (T90) is positive and significant. It indicates that the standard deviation σ_t has increased during the 1990's. Note from (3c) that such an increase is unrelated to the changing censoring effects of the price support program. The coefficients γ_2 and γ_3, capturing the stock effect on price volatility, are negative and highly significant. This provides direct evidence that both private and public stocks tend to reduce price volatility over the sample period. This finding is consistent with the indirect evidence found by Shively. Interestingly, the effects of private stocks on price volatility are found to be much stronger than the effects of public stocks. This suggests that, if we neglect censoring effects, a market liberalization involving a switch from public stocks to private stocks may contribute to stabilizing market prices. In addition, while private stocks may affect negatively both mean price and the variance of price, it is only the latter that exhibits statistical significance. This illustrates the important role played by storage in price stabilization.

Figure 3 demonstrates the performance of the estimated model by comparing the expected prices obtained from (2a) with actual prices. They indicate that the model has a high explanatory power during the sample period. Figure 3 also provides useful information about the changing nature of the U.S. nonfat dry milk market over the last 30 years. It illustrates the stable nonfat dry prices of the 1970s and 1980's when the price support was consistently binding, while it also shows the increased volatility of nonfat dry milk prices in the 1990's.

Next, the standard deviation of nonfat dry milk price ($V(y_t)^{1/2}$) over the sample period was simulated using the estimated model (2b). Figure 4 reports the simulation results. They show large changes in price instability. The standard deviation of nonfat dry milk price was the smallest in the early 1980's. The following two factors contribute to this: (1) during that period, the market volatility was low (as measured by σ_t); and (2) the censoring effects of the price support program were strong and generated a further reduction in price variance. Figure 4 also shows that the standard deviation of nonfat dry milk price was largest in the 1990's. Again, this is due to two factors: (1) in that period, the market volatility (as measured by σ_t) was large and increasing; and (2) the censoring effects of the price support program were moderate as the price support was often lower than the market price. Note that the standard deviation of nonfat dry milk price still fluctuated significantly during the 1990's. This is due in large part to stock effects: the standard deviation σ_t decreases (increases) when stocks are high (low). This validates the important effects of storage behavior on price volatility.

Finally, we investigate the relative role of the price support program in the estimated price variance. This is done by calculating the relative variance $V(y_t)/\sigma_t^2$ from equation (2b). The results are presented in Figure 5. As discussed in section 2, the relative variance $V(y_t)/\sigma_t^2$ is bounded between zero and one: it is equal to one in the absence of censoring, and it becomes close to zero in the presence of strong censoring effects. As expected, Figure 5 indicates that censoring effects are persistent for the most part of sample period except in the middle and late 1990's and they are strongest in the early 1980's (the relative variance is close to zero). This provides evidence that the price support program has contributed to significant reductions in price instability in the U.S. nonfat dry milk market over the last 30 years.

5. Implications

Given the large changes in price instability just documented, it is useful to investigate further implications of our model for price dynamics. The analysis in this section relies mainly on dynamic multipliers. This is done by simulating the effects of changes in selected variables on the path of expected price and the variance of price given in (2a) and (2b). However, note that equation (2a) involves non-linear dynamics. This is because the functions ϕ and Φ are non-linear functions of lagged prices. Due to this non-linear dynamic nature of (2a), all dynamics are "local" in the sense that they depend on the particular path being evaluated. For that reason, we focus our attention on two scenarios: one covering the period starting in September 1985; and one covering the period starting in January 1994. Recall that these two scenarios correspond to two extreme situations related to the nonfat dry milk price support program. The first scenario (≥ 1985.09) can be loosely interpreted as representing "government regime", where the price support is strongly binding. Whereas, the second (≥ 1994.01) represents "market regime", where government purchases are inactive. This interpretation will prove useful in the interpretation of the results below.

First, using (2a) and (2b), we simulated the effects of changing lagged nonfat dry milk stocks (both private and public stocks as measured by CS_{t-1} and GS_{t-1}) on the mean and standard deviation of nonfat dry milk price, Ey_t and $V(y_t)^{1/2}$. The results are reported in Table 2 under the two scenarios. Table 2 reports the effects of a temporary shock in private and public nonfat dry milk stocks (CS_{t-1} and GS_{t-1}) on the current price Ey_t and the standard deviation of the price $V(y_t)^{1/2}$. Under the government regime, the elasticities of mean price with respect to both public and private stocks were found to be negative but small: -0.0068 with respect to private stock, and -0.0062 with respect to public stock. Similarly, under the market regime, the elasticities of mean price with respect to private and public stocks are –0.0124 and –0.0002, respectively. This suggests that such stock effects are very small. This is consistent with coefficient estimates associated with private stock variable in (3b) being negative but not statistically significant. While the public stock effect in (3b) is statistically significant, our elasticity estimates indicate that its marginal effect on mean price is small (i.e., that large changes in public stocks are needed to have a substantial effect on expected price). However, the effects of private and public stocks on price volatility were larger. Under the government regime, the elasticities of $V(y_t)^{1/2}$ with respect to private and public stocks were –5.72 and –4.63, respectively. Under the market regime, however, the elasticity of $V(y_t)^{1/2}$ with respect to public stock is small (-0.0124). These results have two implications. First, stock accumulation in both the private and public sectors contributes to significantly reducing price volatility. The exception is for public stock under the market regime where the effect is estimated to be small (as expected). Second, for both private and public stock this effect is much stronger when the price support is binding. This reflects the fact that the censoring effect is large (small) under the government (market) regime. It identifies important interaction effects between private and public stocks, and government policy on price volatility.

Second, we simulated the effects of a temporary shock in the price of nonfat dry milk. The results are reported in Figure 6 under the two scenarios. Figure 6 shows the dynamic impact of an exogenous change in nonfat dry milk price y_t on the expected future prices Ey_{t+j} and the standard deviation of future prices $V(y_{t+j})^{1/2}$, j = 0, 1, 2, ... It shows that under the "government regime" scenario, changing market prices has small effects on price dynamics and price volatility. This is an intuitive result: it is the situation where the price support is the key determining factor for the market price. However, under the "market regime" scenario, the dynamics look quite different. It shows that short-term price dynamics are significant: significant dynamic adjustments take place in the nonfat dry milk market in the absence of government intervention. As shown in Figure 6, a temporary shock in the nonfat dry milk price generates only a small effect on price volatility under both regimes.

Third, we simulated the effects of a *permanent* shock in the support price in the U.S. nonfat dry market. The results are presented in Figure 7 under the two scenarios. Figure 7 shows the dynamic impact of a *permanent* change in the support price s_t on the expected future prices Ey_{t+j} and the standard deviation of future prices $V(y_{t+j})^{1/2}$, j = 1, 2, 3, ... The support price is found to have large effects on price dynamics and price volatility under the “government regime” scenario. For example, when the support price is binding, a permanent increase in the price support generates almost parallel increase in the nonfat dry milk price in both short and long run. Again, this is intuitive since under the government regime scenario, the price support is the key factor for the market price determination. The dynamic impacts of the support price on $V(y_{t+j})^{1/2}$ appear more complex. Under the “government regime” scenario, the initial effect (j = 1) on the standard deviation is negative and large, suggesting that the censoring effect of the price support program effectively decreases short-term price instability. However, as shown in Figure 7, the next period effect (j = 2) is positive. This can be contributed to the short term overshooting estimated by the model. In other words, an increase in y_t tends to generate a more than proportional increase in y_{t+1}, which reduces the negative censoring effect of the price support on the price variance at time t+1. As demonstrated in Figure 7, in the longer term, the effects of a permanent increase in the price support on $V(y_{t+j})^{1/2}$ are found to be negligible. This suggest that, under the “government regime” scenario, while the price support program may reduce short term price instability, it does not appear to contribute to a significant reduction in long-term price instability. As such, our finding identifies the need to differentiate short run versus long run effects of price stabilization efforts in the analysis of price support program.

Next, we examine the impact of the price support on price dynamics and price volatility under the "market regime" scenario. The impact on price volatility is very small in both short and long run. This is an intuitive result: when the price support is lower than the market price, a permanent increase in support price does not have large effect on price volatility. However, as indicated in Figure 7, the long-term impact of a permanent increase in the price support on expected price is not small (0.6). This suggests that the cumulative impact of a higher support price on expected market price is not negligible even when the level of support price is relatively low. This shows that limited government intervention (in the form of infrequent government purchases taking place only when the price is "very low") can still have a significant effect on long-term price dynamics. This finding suggests that it is possible for government policy to have significant effect on long-term market prices at a relatively low cost to the taxpayers.

6. Concluding Remarks

This paper has investigated econometrically the effects of a price support program and stocks (both private and public) on price dynamics and price volatility. We specified and estimated a dynamic Tobit model under time varying volatility, reflecting the fact that the price support provides a censoring mechanism to price determination. The model is applied to the U.S. nonfat dry milk market. It relies on monthly price and stock data for the period of 1970-2000. One interesting characteristic of this market is its long-standing price support program that has been the subject of some market liberalization in the 1990's. This allows us to examine the impact of market liberalization on price dynamics and price volatility in the presence of private stock as well as public stock.

The econometric analysis provides empirical evidence on the dynamics of nonfat dry milk prices and their changing volatility. First, we found evidence that stock effects are significant and reduce price volatility. While private stocks may affect negatively both mean price and the variance of price, only the latter shows statistical significance, illustrating the important role of storage in price stabilization. Also, as expected, the empirical evidence suggests that public stock accumulation contributes to market stabilization when the support price is binding (as in the "government regime" scenario). In general, such findings are consistent with "stock effects" discussed in the economics of storage (e.g., Williams and Wright; Deaton and Larogue 1992; 1996). Our results indicate how such effects can interact with the price support program. They provide useful insights on the effects of market liberalization.

Second, we document that market liberalization has been associated with a large increase in price volatility (e.g., in the mid1990s). Our analysis provides evidence that the price support program has been effective in reducing price volatility. Third, our simulation results identify some important dynamic aspects of price adjustment in the U.S. nonfat dry milk market under market liberalization. It is found that increasing the price support stimulates expected price but reduces the variance of price. Alternatively, lowering the support price (under market liberalization) tends to increase price volatility. However, we found that such an impact is effective mostly in short-term and tends to disappear in the longer term. In addition, under the market regime scenario (where the support price is below the market price), our analysis indicates that the support price program has a positive but small short-term effect on expected price. But it also indicates that the support program can still contribute to significant changes in the long-run expected prices. This suggests that it is possible for government policy to have long-term effects on market prices at relatively low cost to the taxpayers. While these findings were obtained in the context of the U.S. nonfat dry milk market, it is not clear whether similar results would hold in other markets. Further research is needed to investigate the interaction effects between policy reform, price dynamics and storage behavior.

Appendix

Consider the standardized residual $\varepsilon_t = e_t/\sigma_t = [y_t - f(X_t, \beta)]/\sigma_t$. Using $h_t = [s_t - f(X_t, \beta)]/\sigma_t$, we have

$$E(\varepsilon_t) = [E(y_t) - f(X_t, \beta)]/\sigma_t = h_t \cdot \Phi(h_t) + \phi(h_t), \tag{A1}$$

from (2a). In addition,

$$E(\varepsilon_t^2) = \int_{-\infty}^{h_t} h_t^2\, \phi(u)\, du + \int_{h_t}^{\infty} \varepsilon_t^2\, \phi(u)\, du.$$

From Maddala (p. 365), we have $\int_{h_t}^{\infty} \varepsilon_t^2\, \phi(u)\, du = [1 - \Phi(h_t)] \cdot E[\varepsilon_t^2 | \varepsilon_t > h_t] = [1 - \Phi(h_t)] \cdot [1 + h_t \cdot E(\varepsilon_t | \varepsilon_t > h_t)] = [1 - \Phi(h_t)] \cdot [1 + h_t \cdot \phi(h_t)/(1 - \Phi(h_t))]$. It follows that

$$E(\varepsilon_t^2) = 1 - \Phi(h_t) + h_t \cdot \phi(h_t) + h_t^2 \cdot \Phi(h_t). \tag{A2}$$

Using $V(y_t) = \sigma_t^2 \cdot V(\varepsilon_t) = \sigma_t^2 \cdot [E(\varepsilon_t^2) - (E(\varepsilon_t))^2]$, (A1) and (A2) yield equation (2b).

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Table 1. Parameter Estimates for Heteroscedastic Dynamic Tobit: US Nonfat Dry Milk Price, January 1970-July 2000

Parameters	Definition	Estimates	Standard Errors
β_0	Intercept for the price equation	1.649	(1.239)
β_{t-1}	price of Non-fat dry milk at time t-1	1.505***	(0.064)
β_{t-2}	price of Non-fat dry milk at time t-2	-0.710***	(0.114)
β_{t-3}	price of Non-fat dry milk at time t-3	0.210**	(0.103)
β_{t-4}	price of Non-fat dry milk at time t-4	-0.078	(0.079)
β_{t-5}	price of Non-fat dry milk at time t-5	0.028	(0.063)
β_{t-6}	price of Non-fat dry milk at time t-6	0.106*	(0.064)
β_{t-7}	price of Non-fat dry milk at time t-7	-0.147**	(0.061)
β_{t-8}	price of Non-fat dry milk at time t-8	0.314***	(0.064)
β_{t-9}	price of Non-fat dry milk at time t-9	-0.322***	(0.071)
β_{t-10}	price of Non-fat dry milk at time t-10	0.033	(0.068)
β_{t-11}	price of Non-fat dry milk at time t-11	0.128**	(0.055)
β_{t-12}	price of Non-fat dry milk at time t-12	-0.108***	(0.032)
β_{CS}	Lagged Non-fat dry milk commercial stock (CS_{t-1})	-6.060	(5.097)
β_{GS}	Lagged Non-fat dry milk government stock (GS_{t-1})	-0.888**	(0.418)
β_T	Time trend (TT)	0.127***	(0.027)
β_{Q1}	Dummy for 1st Quarter (Q1)	-0.890**	(0.424)
β_{Q2}	Dummy for 2nd Quarter (Q2)	-0.731**	(0.363)
β_{Q3}	Dummy for 3rd Quarter (Q3)	0.644**	(0.268)
β_σ	Standard deviation (σ_t)	0.133	(0.186)
Intercept	Intercept for the standard deviation equation	3.087***	(0.151)
γ_1	Time trend in the 1990s (T90)	-0.021	(0.019)
γ_2	Lagged Non-fat dry milk commercial stock (CS_{t-1})	-21.387***	(1.727)
γ_3	Lagged Non-fat dry milk government stock (GS_{t-1})	-1.421***	(0.177)
T	355		
Log- likelihood	-602.27		

Note: Standard errors are provided in parentheses, T denotes the number of observations, and asterisks indicate statistical significance at the 10 percent (*), 5 percent (**), and 1 percent (***) level, respectively.

Figure 1. Actual & Support Prices of Nonfat Dry Milk

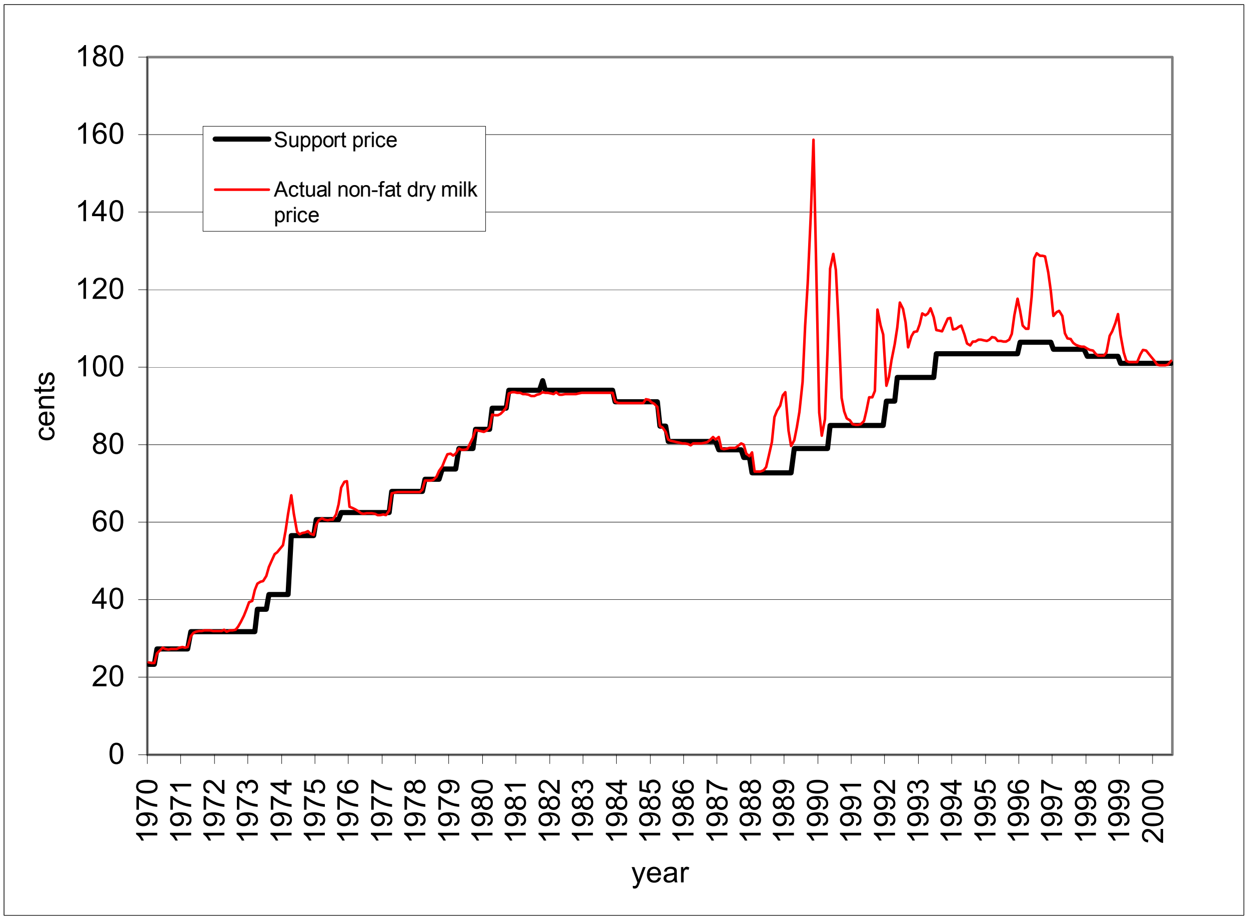

Figure 2. Commercial and Government Stocks of Nonfat Dry Milk

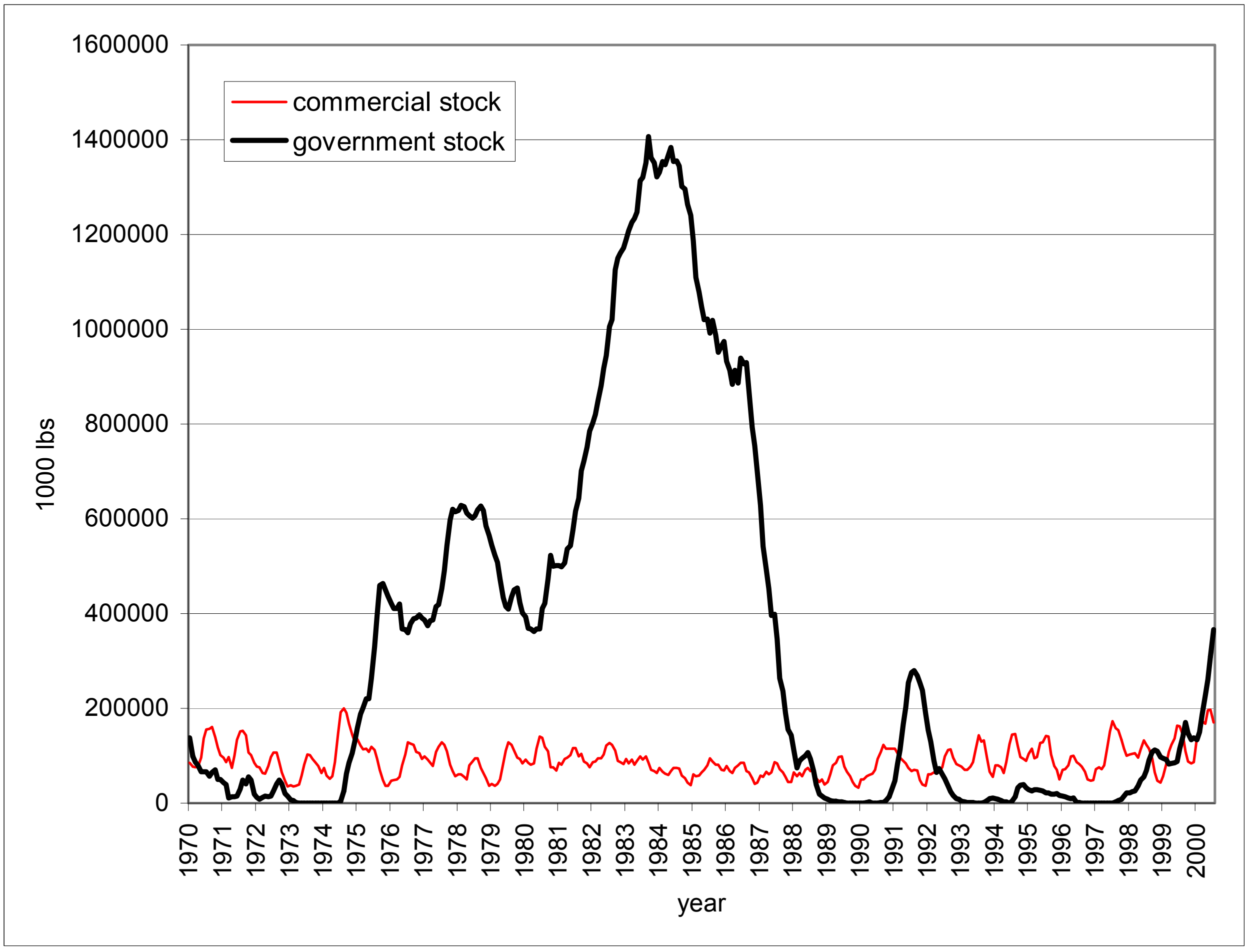

Figure 3. Expected & Actual Prices of Nonfat Dry Milk

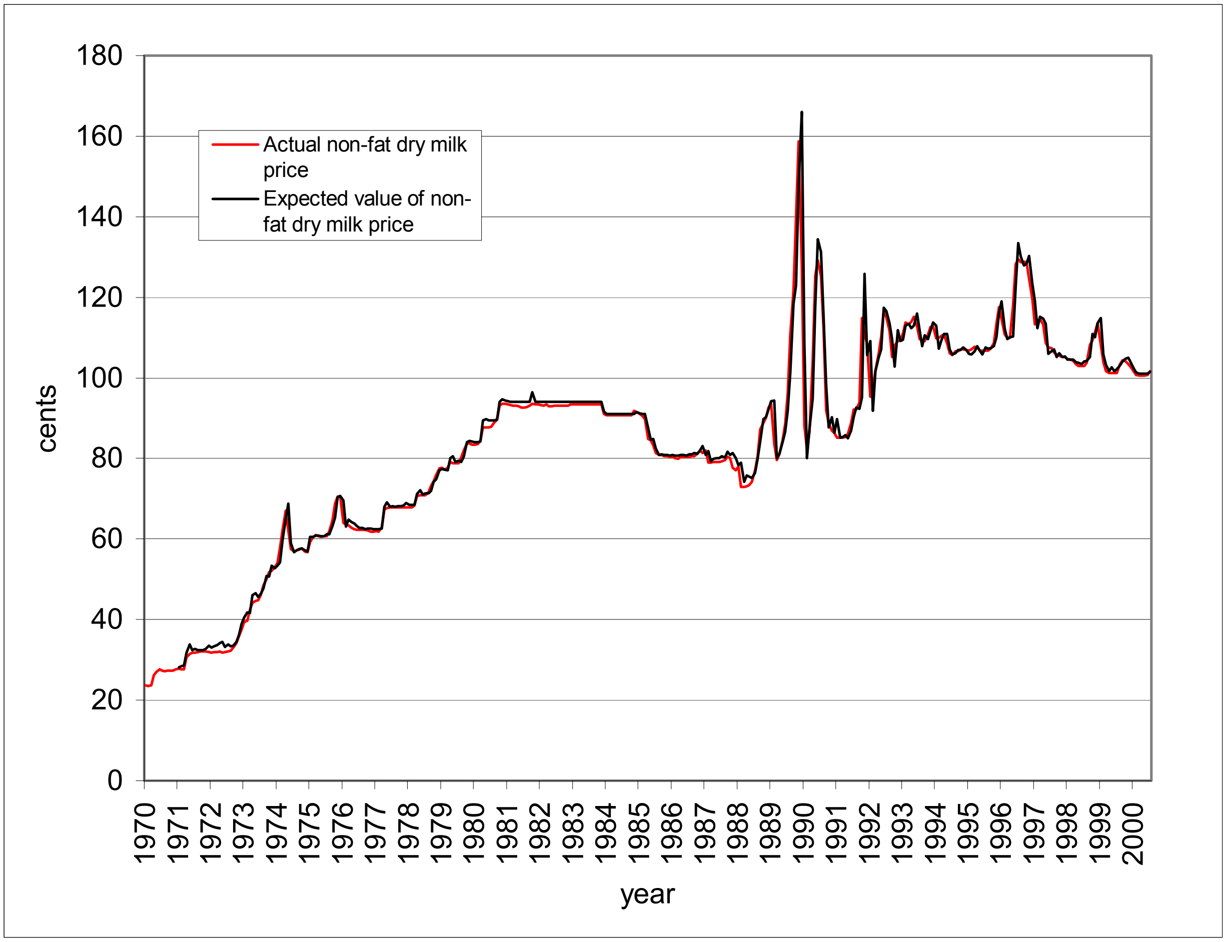

Figure 4. Estimated Standard Deviation of Nonfat Dry Milk Price

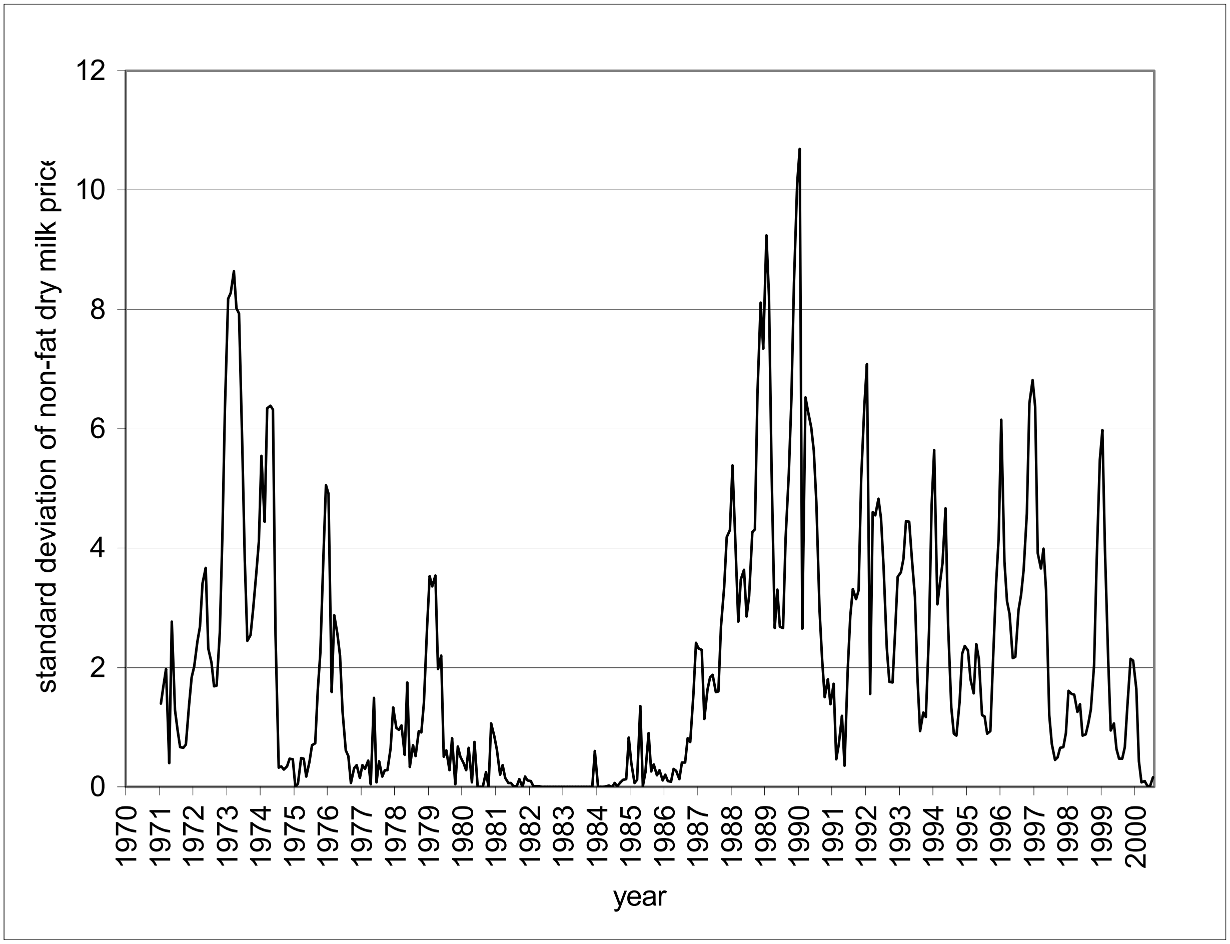

Figure 5. Relative Variance $V(y_t)/\sigma_t^2$ of Nonfat Dry Milk Price due to Censoring

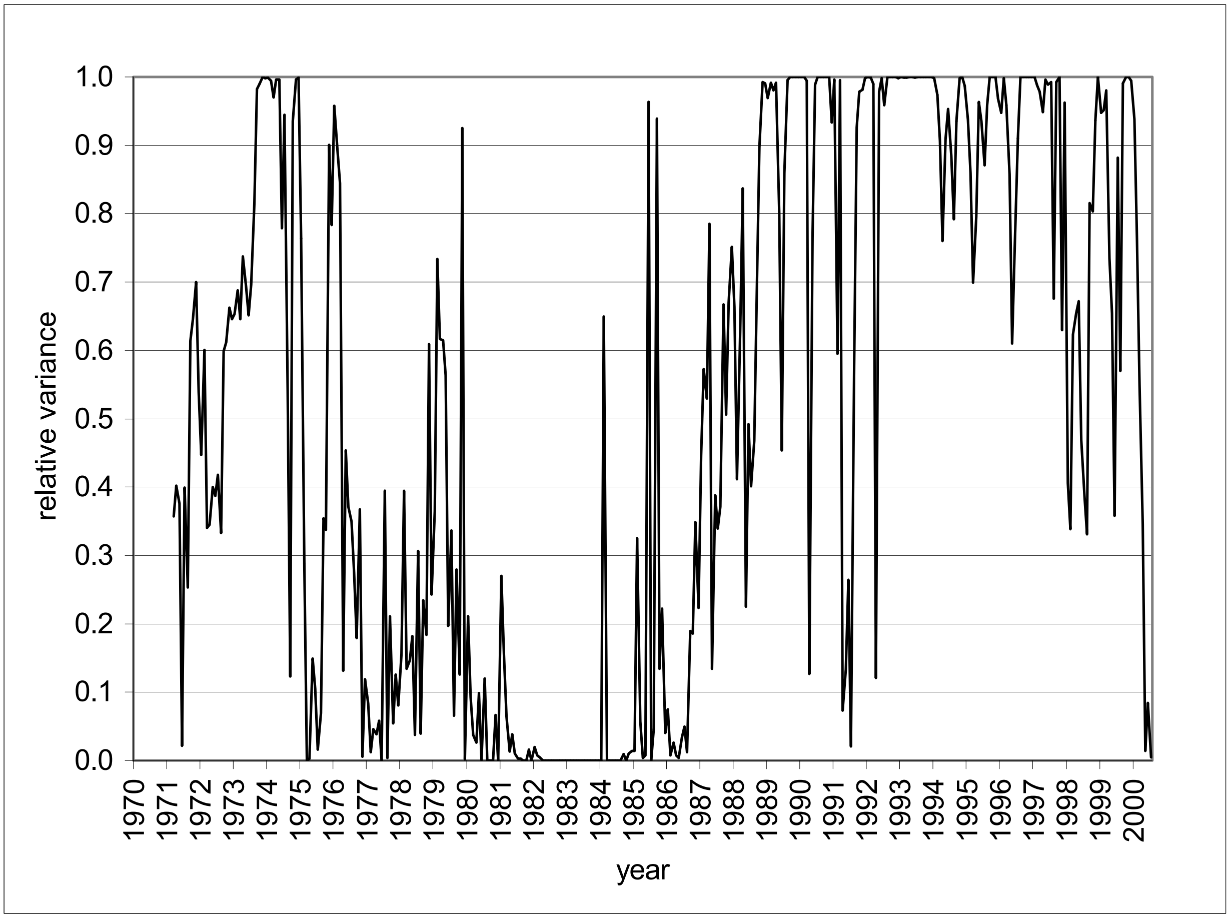

Figure 6. The Effects of Temporary Shock in Nonfat Dry Milk Price on the Expected Future Prices Ey_{t+j} and the Standard Deviation of Future Prices $V(y_{t+j})^{1/2}$

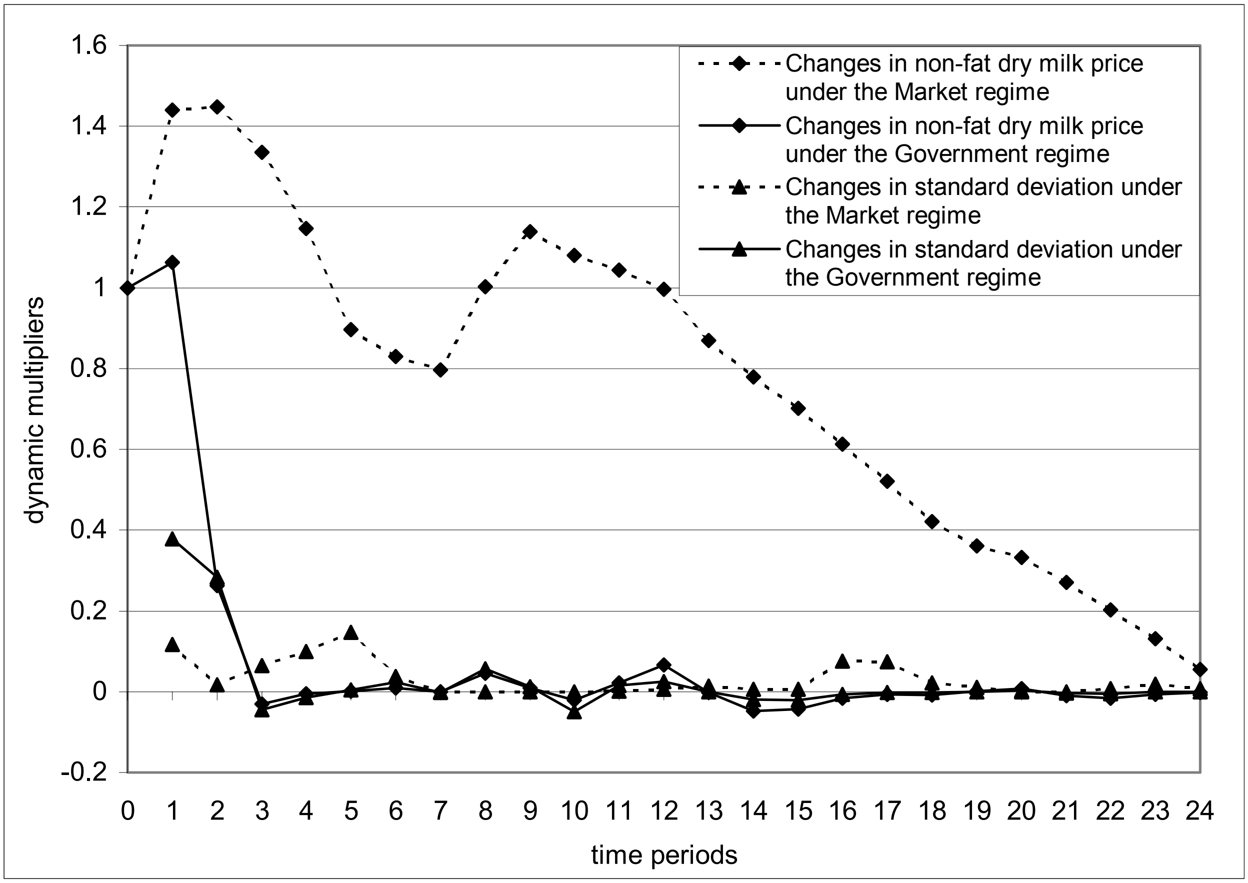

Figure 7. The Effects of a Permanent Shock in the Support Price of Nonfat Dry Milk on the Expected Future Prices Ey_{t+j} and the Standard Deviation of Future Prices $V(y_{t+j})^{1/2}$

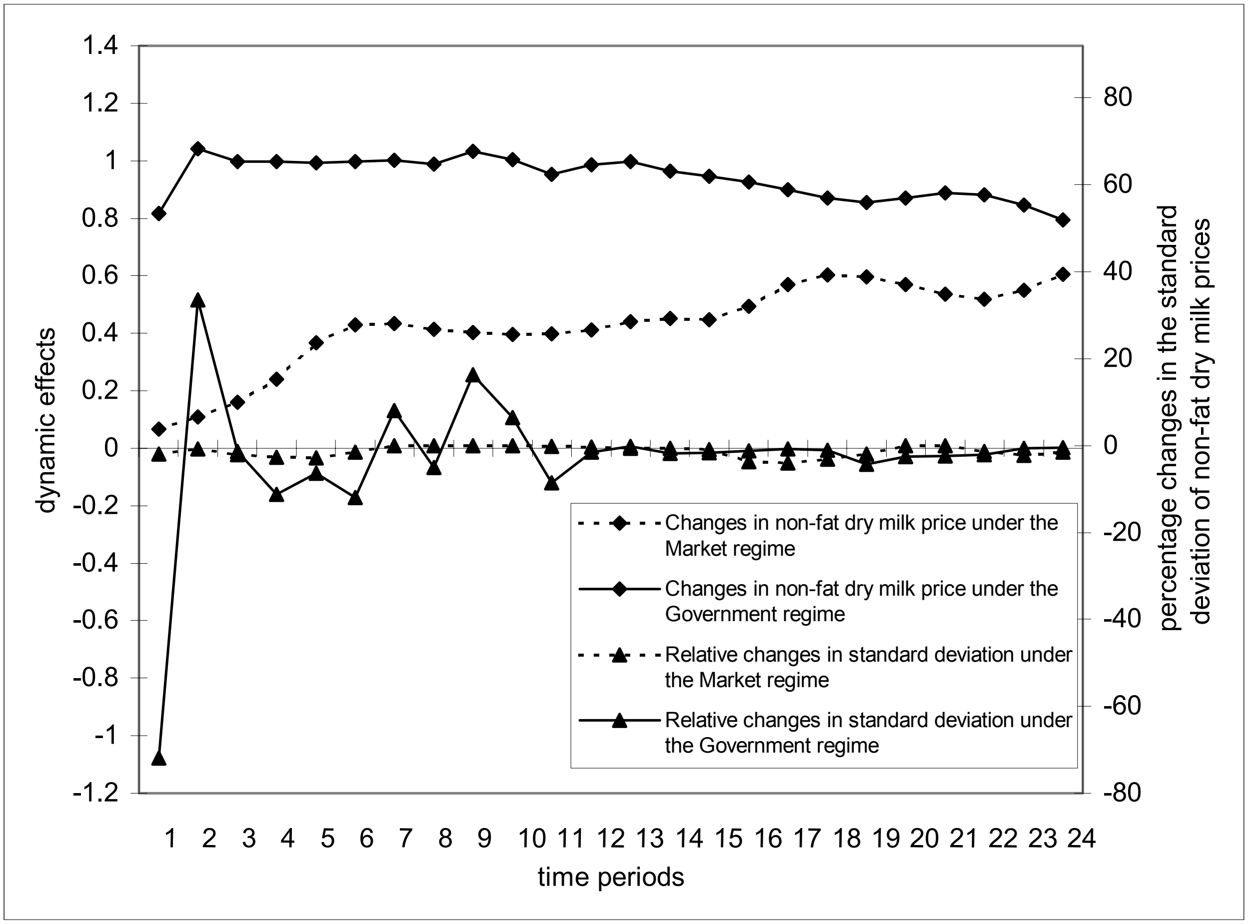

Table 2. The Mean and Standard Deviation Effects of Temporary Shock (10%) in Commercial and Government Stock

		Commercial Stock	Government Stock
Market regime	Standard deviation effects	-14.467	-0.124
	Mean price effects	-0.124	-0.002
Government regime	Standard deviation effects	-57.187	-46.302
	Mean price effects	-0.068	-0.062

Footnotes

[1] The corresponding supply-demand structural forms have been analyzed by Shonkwiler and Maddala, and Holt and Johnson.

[2] An alternative dynamic Tobit specification is $X_t = (Y_t^*, x_t)$, where $Y_t^* = (y_{t-1}^*, y_{t-2}^*, \ldots)$ is a vector of lagged latent variables, and x_t denotes other explanatory variables (Lee; Wei). As noted by Lee, this includes as a special case the Tobit model under autocorrelated error terms (Zeger and Brookmeyer). We did not rely on this specification for two reasons: 1/ using lagged latent variables means that the likelihood function involves multiple integrals (which requires switching from the standard maximum likelihood method to simulated estimation methods); and 2/ estimating time-varying σ_t becomes more difficult in this context (see Lee).

[3] We use wholesale price of nonfat dry milk for human food.

[4] Except for the period of the early 1980's, the Secretary of Agriculture had discretion in making some adjustments in the support price depending on market conditions and government stocks.

[5] Alternative specifications were attempted for σ_t. First, the observed increase in price volatility toward the end of the sample period (see Figure 1) meant that autoregressive structures for σ_t were found to be non-stationary. For that reason, we elected not to choose a GARCH structure for the error term in our model (e.g., following Engle or Bollerslev). Second, under censoring, note that ARCH processes generate multiple integrals in the sample likelihood function. Since these integrals are not easily evaluated analytically, ARCH would imply a need to switch from the standard maximum likelihood method to simulated estimation methods. In this context, Lee found that the estimation of ARCH parameters in a Tobit model can be difficult.

[6] As shown in equation (2a), censoring generates non-linear dynamics, where the forward path of expected prices depends on the support price in a non-linear fashion.

[7] All roots are complex. The pair of dominant roots is $[0.9515 \pm 0.0840\ (-1)^{1/2}]$, with modulus 0.9552. They imply cyclical patterns.