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An Econometric Analysis of the Effects of Market Liberalization on Price Dynamics and Price Volatility

by

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and

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Abstract: The paper investigates price dynamics under market liberalization, with a focus on the effects of lowering price floors. We analyze price dynamics by specifying and estimating a dynamic Tobit model under time-varying volatility, where the market price is censored by a government-set support price. The model is applied to the U.S. butter market over the last three decades. The econometric results show how the price support program affects both expected prices and the volatility of prices. It is found that the censoring effects of a price support program can be significant and large even if the price support is set relatively low.

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

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1. Introduction

The efficiency of complete competitive markets is well known. It has generated a dominant view among economists that market liberalization is desirable. This has stimulated a general move toward market liberalization and a reduced role for government policy in allocating resources. Market liberalization has happened to domestic policy as well as trade policy. As a result, there has been an increased reliance of market mechanisms for resource allocation in most sectors of the economy.

This paper presents an economic analysis of the effects of a particular type of market liberalization: the reduction of price floors. Price floors have been a key feature of U.S. agricultural policy since the 1930's. They tend to stabilize and increase the price received by U.S. farmers and raise farm income (e.g., Shonkwiler and Maddala; Holt and Johnson). Price support programs are implemented through government purchase of storable products. First, a commodity support price is set as part of agricultural policy. Second, a government agency stands ready to purchase (and store) any amount of the commodity at the support price level. In the case where the market price is greater than the support price, there is no government purchase. However, if the market price were to fall below the support price, then government purchases take place (financed by the taxpayers). Government purchases stimulate demand and increase public stocks. Government stocks get eventually released: either they are put back on the market when the market price rises above the support price, or they are sold at subsidized prices on domestic markets (e.g., as part of the domestic food programs) or on the world market. Until the 1990's, U.S. government price support programs were active most of the time for corn, wheat, and the dairy sector (where support prices are set for butter, non-fat dry milk and American cheese). However, a market liberalization policy was implemented in U.S. agriculture in the 1990's. As a result, agricultural price support levels were lowered significantly. This raises the question: how did such market liberalization affect U.S. agricultural prices, including both price level and price volatility?

The objective of this paper is to investigate price dynamics under market liberalization, with a focus on the effects of recent policy reform. The approach is applied to U.S. butter market. 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). Our paper innovates in several ways. First, we provide a refined reduced-from investigation of price dynamics under regime switching. Second, we investigate the changing price volatility and its interaction with the price support program over the last few decades. Third, our analysis provides some new and useful insights on the levels and instability of butter prices both before and after the policy reform of the 1990's. Finally, our empirical findings indicate how market liberalization has affected butter prices over the last few years.

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 US butter market, based on monthly data for the period 1970-2000. The econometric results are presented in section 4. They show how the price support program affects 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. It is found that the long term censoring effects of the butter price support program can be significant and large even if the price support is set relatively low.

2. The Model

Consider a commodity market where the price is subject to a government price support program. Let y_t denote the market price at time t. The price support program involves a floor price s_t reflecting government policy at time t. Practically, 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 stands ready to buy (and usually store) 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 model

$$y_t = \max\{y_t^*, s_t\}, \qquad (1a)$$

$$y_t^* = f(X_t, \beta) + e_t \qquad (1b)$$

where y_t^* is a latent price variable at time t, X_t is a vector of explanatory variables, β is a $(k \times 1)$ vector of parameters to be estimated, and e_t is an error term distributed as $N(0, \sigma_t^2)$.

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 $I_t = 1$ if $y_t^* > s_t$, and $I_t = 0$ otherwise. From (1a), the latent variable y_t^* is observed only if $I_t = 1$. 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 $I_t = 0$. 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.

We focus our attention on the case where (1a) and (1b) give the reduced form for price determination.[1] In this context, 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.[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 specification (1a)-(1b) for the mean and variance of price y_t will be of interest. Let $h_t = [s_t - f(X_t, \beta)]/\sigma_t$. Denote the probability that the censored variable y_t^* is unobserved by $\text{Prob}(I_t = 0) = \text{Prob}[e_t < s_t - f(X_t, \beta)] = \Phi(h_t)$, where $\Phi(\cdot)$ is the standard normal distribution function. Then, from (1a)-(1b), the expected value of y_t is

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

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

where $E(e_t | e_t > s_t - f(X_t, \beta))] = \sigma_t \cdot \phi(h_t)/(1 - \Phi(h_t))$, $\phi(\cdot)$ being the density function of the standard normal variable (see Maddala, p. 365). Expression (2a) gives the intuitive result that expected price $E(y_t)$ is a weighted average of the support price s_t and of the expected market price conditional on $I_t = 1$. The weights involve the probability of censoring, $\Phi(h_t)$, e.g., the probability of facing the government regime at time t.

In addition, the variance of y_t is (see the proof in the Appendix)

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

Equation (2b) implies that the relative variance $[V(y_t)/ \sigma_t^2]$ equals $[1-\Phi(h_t) + h_t \cdot \phi(h_t) + h_t^2 \cdot \Phi(h_t) - [h_t \cdot \Phi(h_t) + \phi(h_t)]^2]$: it 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.

Equations (2a) and (2b) provide useful insights on the role of dynamics. To see that, consider the simple specification for (1b): $f(\cdot) = a_0 + a_1 y_{t-1}$. Then, using (2a), $\partial Ey_t/\partial y_{t-1} = a_1 \cdot [1 - \Phi(h_t)] + \partial\Phi(h_t)/\partial y_{t-1} \cdot [s_t - f_t] + \sigma_t \cdot \partial\phi(h_t)/\partial y_{t-1}$. This shows that the dynamics is non-linear since the distribution function $\Phi(\cdot)$ is non-linear. This means that, in general, local dynamics can vary depending on the point of evaluation. This will be further illustrated below in our empirical analysis.

Finally, note that, when working with lagged actual prices and independently distributed error terms e_t, the likelihood function of sample information involves only simple integrals (Maddala, chapter 6). This means that model (1a)-(1b) can be estimated by standard maximum likelihood estimation. With $X_t = (y_{t-1}, \ldots, y_{t-m}, x_t)$, this will allow us to consider more complex dynamics by considering a larger number of lags m. The choice of the maximum lag m will be discussed below.

3. An Application to the Butter Market

In this section, we apply our analysis to the dynamics of U.S. butter prices. We investigate the determinants of butter prices with a special focus on the role of the government price support program. This is done in the context of a heteroscedastistic Tobit model allowing for endogenous regime switching and time varying volatility. The analysis is based on monthly data for the period January 1970-July 2000. Monthly butter prices (measured in cents/lb.) are obtained from the U.S. Department of Agriculture (USDA).[3] During these three decades, the butter price was at the support price level 47.2 percent of the time. Two extreme periods can be identified: the early 1980's when the market price was always at the support price; and the late 1990's when the market price was always above the support price (see Figure 1). 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, market liberalization policy meant a large decline in the support 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] We also investigate the influence of butter stocks on prices. For that purpose, monthly butter stock data were obtained from National Agricultural Statistics Service and Agricultural Stabilization and Conservation Service, USDA. This stock series is measured in million lbs at the beginning of every month.

Our analysis relies on the Tobit specification (1a)-(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. In the case where $\bar{\gamma} \neq 0$, this allows for heteroscedasticity, where z_t affect the volatility of prices. We consider the following specification. First, 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 butter market. Second, we introduce lagged butter stock in x_t. The lagged stock variable, ST_{t-1}, captures stock effects. From the economics of storage (e.g., Williams and Wright), we expect that higher (lower) stock at time t-1 would tend to reduce (increase) the market price at time t. 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 possibly affects the *expected value* of butter 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 butter stock (ST_{t-1}).[5] A time trend for the 1990's (T90 equals 1 for 1990, 2 for 1991, 3 for 1992, … , 11 for 2000, and zero otherwise) is intended to capture possible changes in market instability during the 1990's. The lagged stock variable ST_{t-1} can reflect the effects of stocks on price volatility. Again, from the economics of storage (e.g., Williams and Wright), larger (smaller) stocks may be expected to generate lower (higher) price volatility. As such, our Tobit model specification examines the effects of stocks on both mean price and price volatility in the butter market.

For butter price at time t, this generates the following model:[6]

$$y_t^* = \beta_0 + \beta_T\, TT + \beta_{Q1}\, Q_1 + \beta_{Q2}\, Q_2 + \beta_{Q3}\, Q_3 + \sum_{k=1}^{m} \beta_k\, y_{t-k} + \beta_S\, ST_{t-1} + \beta_\sigma\, \sigma_t + e_t, \qquad (3a)$$

$$\sigma_t = \exp[\gamma_0 + \gamma_1\, T90 + \gamma_2\, ST_{t-1}], \qquad (3b)$$

where y_t^* is the latent butter 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 (3a) 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 stock ST_{t-1}, and σ_t as intercept shifters. As such, equations (3a)-(3b) provide an extension of such a model in the presence of censoring and conditional heteroscedasticity. They constitute the econometric specification used below in the empirical investigation of the impact of price support program on price dynamics in the U.S. butter market.

4. Econometric Results

Model (3a)-(3b) was applied to the U.S. butter market (1970-2000) and estimated by maximum likelihood. Assuming a correct specification, this generates consistent and asymptotically efficient parameter estimates. The choice of the order of the AR process (m) in (3a) was made using the Schwarz criterion (Judge et al. p. 426). This involves choosing m so as to maximize [ln(maximum likelihood) - K · ln(T)/2], where K is the number of parameters and T is the number of observations. The Schwarz criterion chose m = 9. Thus, the analysis below is based on the dynamic Tobit specification (3a)-(3b) with m = 9.[7]

We investigated the presence of heteroscedasticity in the model. This was done by testing the null hypothesis that $\gamma_1 = \gamma_2 = 0$ in (3b), under the maintained hypothesis that $\beta_\sigma = 0$ in (3a). Using a likelihood ratio test, we obtained a test statistic for this hypothesis of 197.52. Under the null hypothesis of homoscedasticity, 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. Thus, we strongly reject the null hypothesis of homoscedasticity for butter prices. In other words, we find strong empirical evidence of time varying volatility in butter 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 model; see equations (2a)-(2b)).

The parameter estimates of the heteroscedastic dynamic Tobit model (3a)-(3b) are presented in Table 1. The lagged price effects exhibit statistical significance for lags 1, 2 and 7.

Note that β_1, the coefficient of y_{t-1}, equals 1.223, suggesting an initial overreaction to a recent price change. However, in the absence of censoring,[8] the roots of the estimated AR(9) are all in the unit circle,[9] suggesting that the model is stationary. The time trend parameter is negative but not statistically significant. The lagged stock variable has a negative impact on latent price as expected. However, its effect is not 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.

The estimated parameters of the standard deviation equation are all highly significant. The parameter 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 (2b) that such an increase is unrelated to the changing censoring effects of the price support program (see below). Finally, the parameter γ_2 for the stock effect (ST_{t-1}) is negative and highly significant. As expected, it means that stocks have a negative effect on price volatility. It is of interest to note that, while 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.

To evaluate the performance of the estimated model, the expected prices obtained from (2a) were calculated and compared with actual prices. The results are presented in Figure 2. They indicate that the model has a high explanatory power during the sample period. Figure 2 also provides useful information about the changing nature of the U.S. butter market over the last 30 years. It illustrates the stable and relatively high butter prices of the early 1980's, when the price support was consistently binding.[10] It also shows clearly the increased volatility of butter prices in the late 1990's.

Finally, using (2b), the estimated model was used to simulate the standard deviation of butter prices ($V(y_t)^{1/2}$) over the last 30 years. The results are presented in Figure 3. They show large changes in price instability. The standard deviation of butter price was the smallest in the early 1980's. This is due to two factors: 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 3 also shows that the standard deviation of butter price was largest in the late 1990's. Again, two factors contribute to this result: 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 much lower than the market price. Note that the standard deviation of butter 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 private stocks are high (low). This shows the important effects of storage on price volatility.

5. Implications

Given the large changes in price instability just documented, it is useful to investigate further some implications of our model. First, one would like to know: what is the relative role of the price support program in the estimated price variance? To answer this question, we calculated the relative variance $V(y_t)/\sigma_t^2$ from equation (2b). It is reported in Figure 4. 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 can become close to zero in the presence of strong censoring effects. As such, [1 -

$V(y_t)/\sigma_t^2]$ can be interpreted as a measure of the relative effect of censoring on price instability. As expected, Figure 4 shows that censoring effects are strongest in the early 1980's, weakest in the late 1990's, and intermediate in other periods. It also documents that the price support program has contributed to significant reductions in price instability in the U.S. butter market over the last 30 years.

Additional insights can be obtained from the model by evaluating its dynamic implications. 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, equation (2a) involves non-linear dynamics (since the functions ϕ and Φ are non-linear functions of lagged prices). As a result, all dynamics are "local" in nature as they depend on the particular path being evaluated. For that reason, we focus our attention on two scenarios: one covering the period starting in February 1981; and one covering the period starting in August 1995. Given our earlier discussion, these two scenarios correspond to two extreme situations related to the butter price support program. The first scenario (≥ 1981.02) can be loosely interpreted as representing "government regime" (where the price support is strongly binding), while the second (≥ 1995.08) represents "market regime" (where the price support is much lower than the market price). This interpretation will prove useful in the evaluation of the results below.

First, using (2a) and (2b), we simulated the effects of a temporary shock in the price of butter. The results are reported in Figure 5 under the two scenarios. Figure 5 shows the dynamic impact of an exogenous change in butter 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, ... 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. Short-term price dynamics are significant. After a one-period overshooting, the effects on expected butter price remain positive and large for several months. This indicates that significant dynamic adjustments take place in the butter market in the absence of government intervention. Figure 5 also indicates that a temporary shock in the butter price has only a small effect on butter price volatility under the "market regime" scenario.

Second, we simulated the effects of a *permanent* shock in the support price. The results are presented in Figure 6 under the two scenarios. Figure 6 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, ... It indicates that the support price has large effects on price dynamics and price volatility under the "government regime" scenario. As expected, when the support price is binding, a permanent increase in the price support translates to an almost parallel increase in the butter price in the short run as well as in the longer run. Interestingly, the dynamic impacts of the support price on $V(y_{t+j})^{1/2}$ are more complex. Under the "government regime" scenario, the initial effect (j = 1) on the standard deviation is negative and large. This means that the censoring effect of the price support program is effective in decreasing short-term price instability. However, the next period effect (j = 2) is positive (see Figure 6). This is due in part to the short term overshooting estimated by the model: 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. Beyond time t+1, the effects of the price support on price variance are in general negative and small (although they are still found to be positive for two periods). 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 reduces short term price instability, it does not appear to contribute to a significant reduction in long term price instability. In other words, our results show that, if the price support program generates price stabilization benefits, such benefits would be obtained only in the very short term and would dissipate in the longer term. Such a finding stresses the need to distinguish between short run versus long run effects in the analysis of government policy.

Figure 6 also shows the impact of the price support under the "market regime" scenario. As expected, it indicates that the support price has only small short term effects on butter price dynamics (Ey_{t+j}) and price volatility ($V(y_{t+j})^{1/2}$) when the price support is lower than the market price. This small impact is also found in the long term with respect to the standard deviation of price. However, Figure 6 shows that the long-term impact of a permanent increase in the price support on expected price is relatively large (0.8). This indicates that the cumulative impact of a higher support price on expected market price is *not negligible* even if the support price is set relatively low (as in the "market regime"). In this case, long-term effects are found to be large even in the presence of relatively small short-term effects. This is a new and interesting result. It stresses the importance of a proper characterization of price dynamics under government intervention. This result indicates that the price support program can contribute to long-term price enhancement even if the price support does not bind most of the time. It shows that relatively infrequent government purchases (taking place only when the market price is very low) can still have a significant effect on long term prices. This means that it is possible for government policy to affect long-term market behavior at a relatively low cost to the taxpayers. Since such effects are obtained only in the long term, this stresses the need for a refined dynamic analysis of government policy.

Finally, we used (2a) and (2b) to simulate the effects of changing butter stocks (as measured by ST) on the mean and standard deviation of butter price, Ey_t and $V(y_t)^{1/2}$. The elasticity of mean price with respect to stocks was found to be negative but small: -0.002 under the "government regime" scenario, and -0.006 under the "market regime" scenario. The effects of stocks on price volatility were larger. The elasticity of $V(y_t)^{1/2}$ with respect to stock was -1.71 under the "government regime", and -0.06 under the "market regime". This has two implications. First, stock accumulation contributes to reducing price volatility. Second, 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 of storage and government policy on price volatility.

6. Concluding Remarks

This paper has presented an econometric analysis of the effects of a price support program on price dynamics and price volatility. It involves specifying and estimating a dynamic Tobit model under time varying volatility. The model reflects the fact that the price support provides a censoring mechanism to price determination, which affects for both expected price and the variance of price. The model is applied to the U.S. butter market, using monthly data for the period 1970-2000. One interesting characteristic of this market is its long-standing price support program that has been subject to significant market liberalization in the 1990's.

The econometric analysis provides empirical evidence on the dynamics of butter prices and their changing volatility. It is found that market liberalization has been associated with a large increase in price volatility. Part of this increase is attributed to policy reform. Our analysis uncovered some important dynamic aspects of price adjustments in the butter market under market liberalization. In general, through its censoring effect, a ceteris paribus rise in the price support stimulates expected price but decreases the variance of price. Alternatively, lowering the support price tends to increase price volatility. However, we found that such an effect is mostly short-term and tends to dissipate in the longer term. In addition, when the support price is set relatively low and below the market price, we found that the support price program has a small short-term positive effect on expected price. However, the evidence suggests that it can still contribute to significantly higher expected prices in the long run. This indicates that it is possible for government policy to affect long-term market behavior at a relatively low cost to the taxpayers. We also explored the effects of stocks on price volatility. The findings are consistent with “stock effects” discussed in the economics of storage (e.g., Williams and Wright). Further, our results showed how such effects vary under market liberalization. Our analysis points to the existence of significant interactions between market dynamics, price level, price volatility, and policy reform. While our empirical results are specific to the butter market, they suggest a need for further refined research on the dynamics of market liberalization and its implications for price dynamics and volatility.

Appendix

Consider the standardized residual $\varepsilon_t = e_t/\sigma_t = [y_t - f(X_t, \beta)]/\sigma_t$, which is distributed N(0, 1). Using $h_t = [s_t - f(X_t, \beta)]/\sigma_t$, we have

$$E(\varepsilon_t) = [E(y_t) - f(X_t, \beta)]/\sigma_t,$$

$$= h_t \cdot \Phi(h_t) + \phi(h_t), \qquad \text{(A1)}$$

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

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

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 Butter Price, January 1970-July 2000

Parameters	Definition	Estimates	Standard Errors
β_0	Intercept for the price equation	0.680	(1.672)
β_{t-1}	price of butter at time t-1	1.223***	(0.071)
β_{t-2}	price of butter at time t-2	-0.433***	(0.110)
β_{t-3}	price of butter at time t-3	0.195*	(0.010)
β_{t-4}	price of butter at time t-4	-0.017	(0.079)
β_{t-5}	price of butter at time t-5	-0.215*	(0.116)
β_{t-6}	price of butter at time t-6	0.026	(0.137)
β_{t-7}	price of butter at time t-7	0.349***	(0.131)
β_{t-8}	price of butter at time t-8	-0.067	(0.126)
β_{t-9}	price of butter at time t-9	-0.078	(0.076)
β_S	Lagged butter stock (ST_{t-1})	-0.292	(0.283)
β_T	Time trend (TT)	-0.046	(0.075)
β_{Q1}	Dummy for 1st Quarter (Q1)	-3.199***	(01.010)
β_{Q2}	Dummy for 2nd Quarter (Q2)	-1.342	(0.950)
β_{Q3}	Dummy for 3rd Quarter (Q3)	3.334***	(0.739)
β_σ	Standard deviation (σ_t)	0.184	(0.228)
Intercept	Intercept for the standard deviation equation	1.501***	(0.104)
γ_1	Time trend in the 1990s (T90)	1.574***	(0.148)
γ_2	Lagged butter stock (ST_{t-1})	-0.079***	(0.029)
T	358		
Log- likelihood	-735.77		

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. Expected & Support Prices of Butter

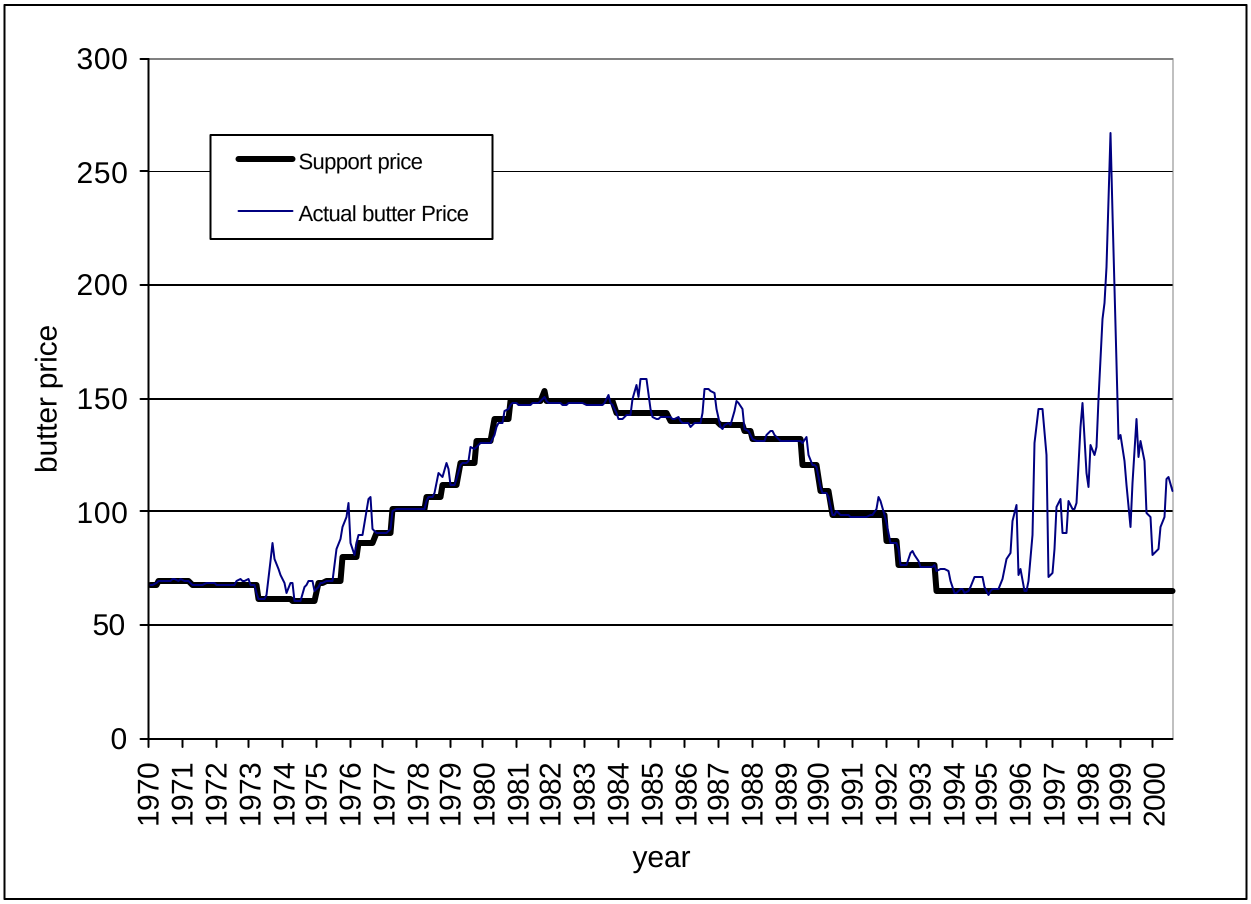


Figure 2. Expected & Actual Prices of Butter

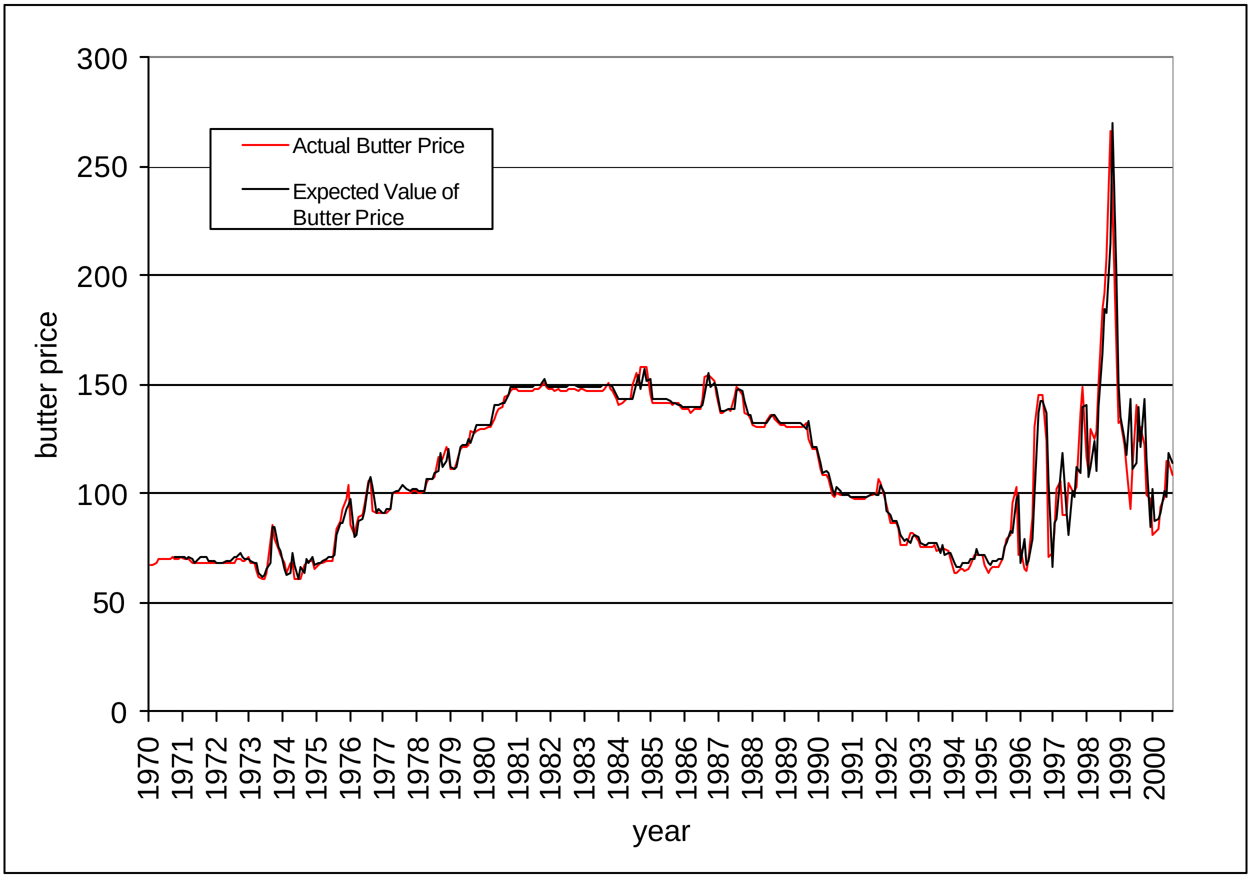


Figure 3. Estimated Standard Deviation of Butter Price

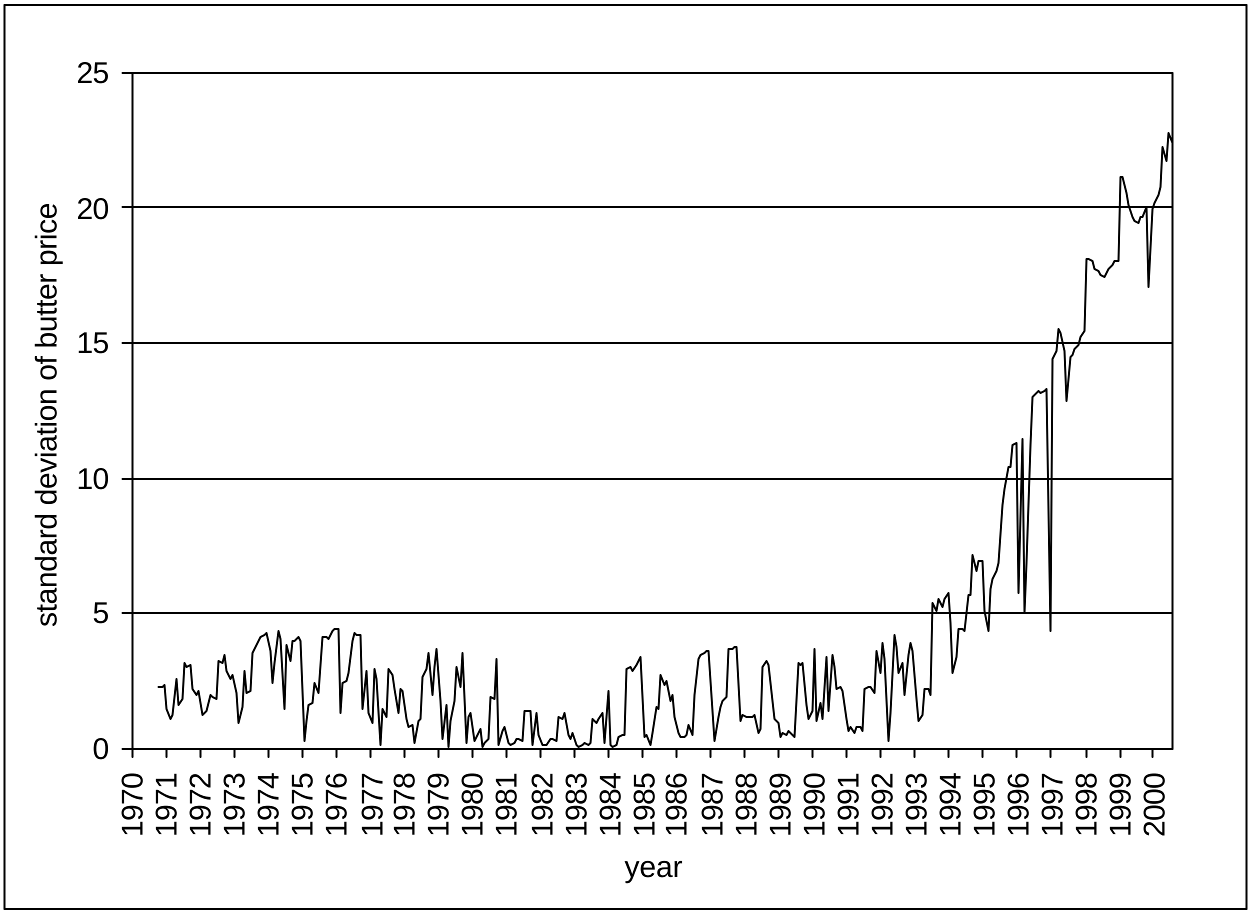


Figure 4. Relative Variance $V(y_t)/s_t^2$ of Butter Price due to Censoring

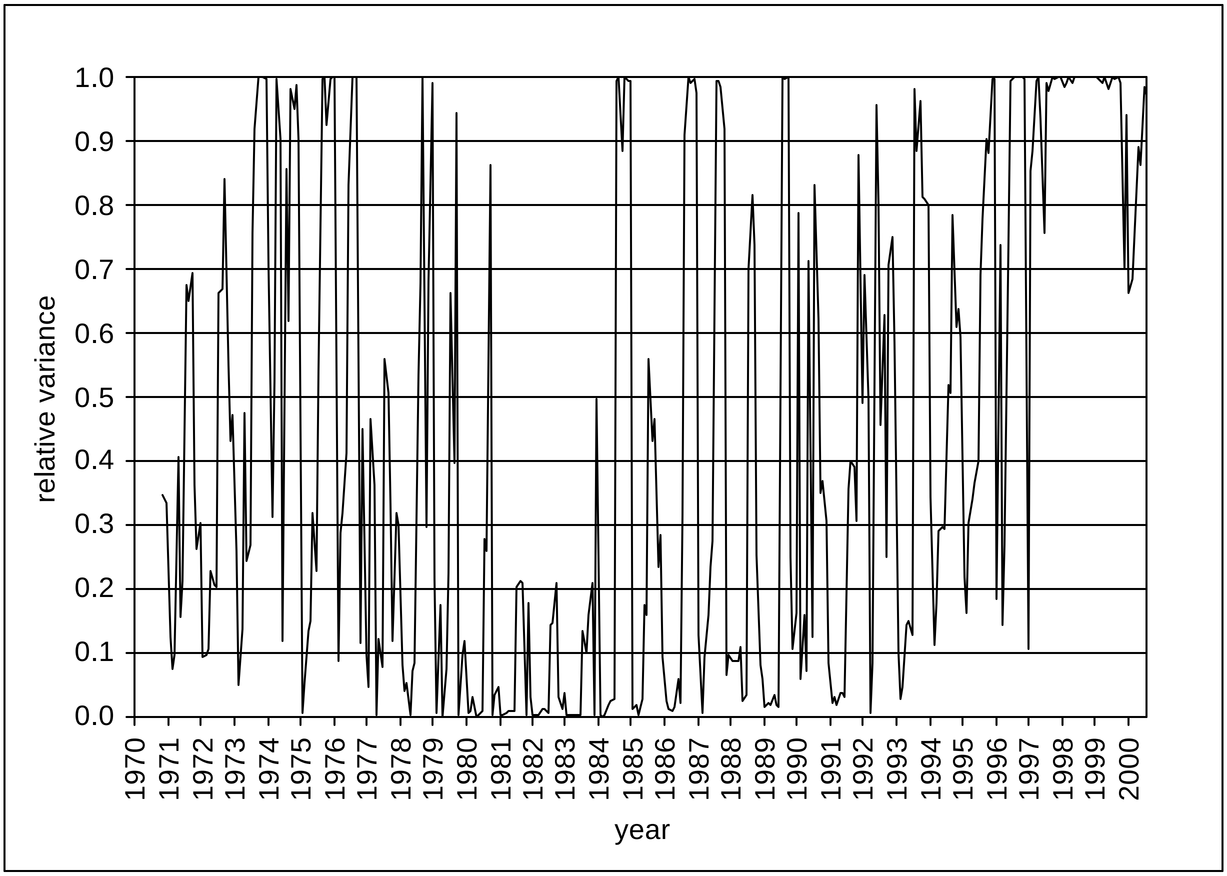


Figure 5. The Effects of Temporary Shock in Butter Price on the Expected Future Prices Ey_{t+j} and the Standard Deviation of Future Prices $V(y_{t+j})^{1/2}$

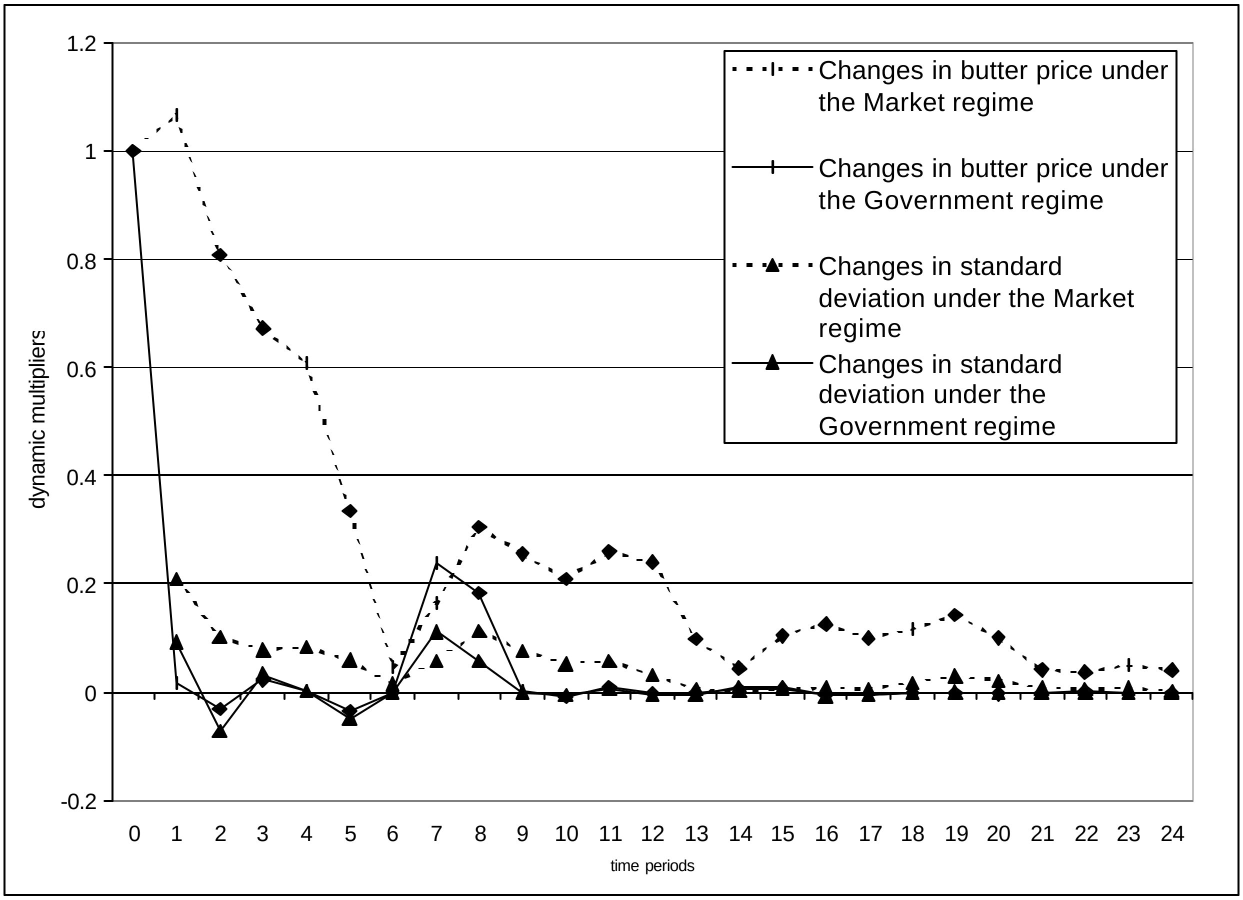
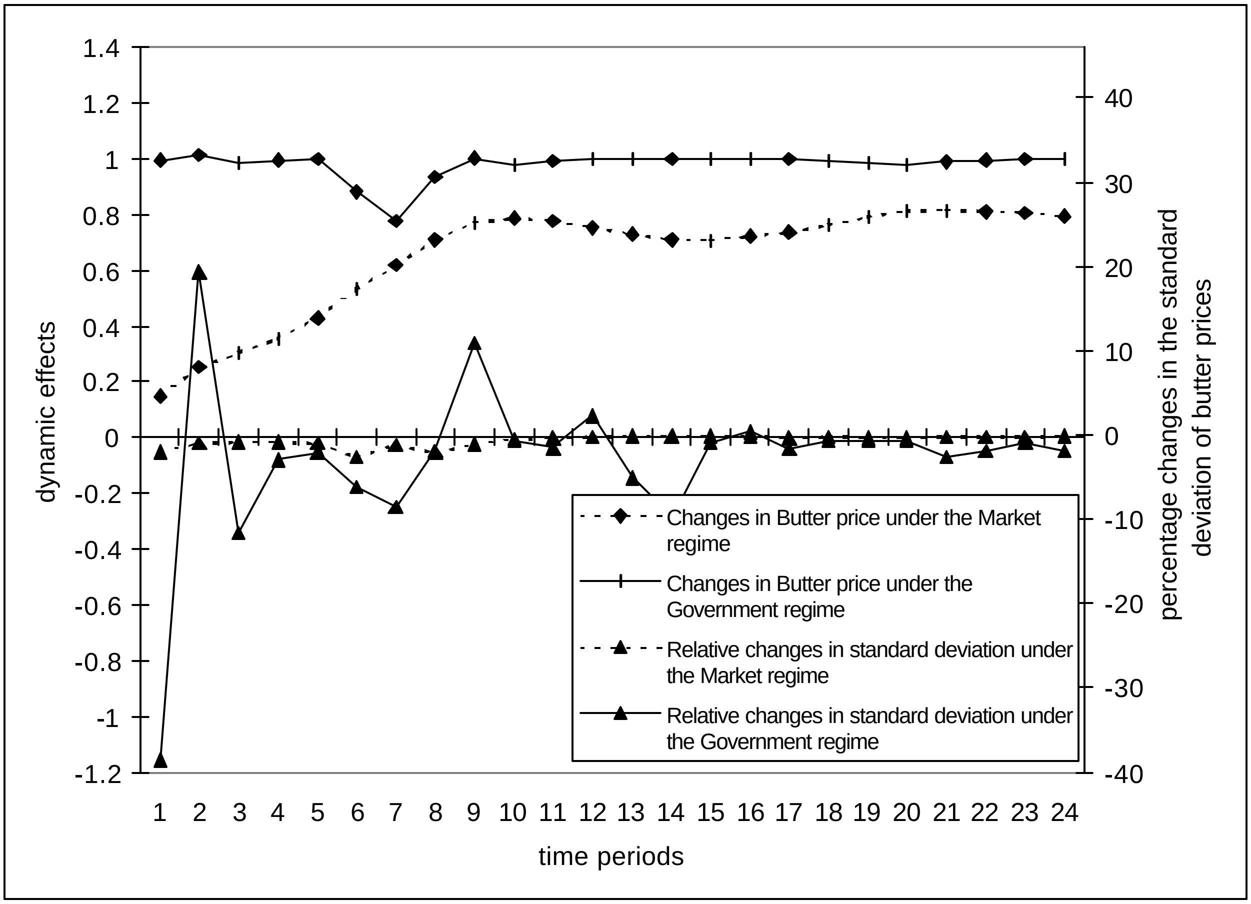


Figure 6. The Effects of a Permanent Shock in the Support Price of Butter on the Expected Future Prices Ey_{t+j} and the Standard Deviation of Future Prices $V(y_{t+j})^{1/2}$



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] The market price for butter is for grade A butter in Chicago from January 1970 to November 1998. Since the grade A price series was discontinued in November 1998, (adjusted) grade AA butter prices in Chicago were used for the period of December 1998 to July 2000.

[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] We also explored the case where stock effects in (3a)-(3b) may differ between private stocks and public stocks. After introducing private stock and public stock separately in (3a)-(3b), we

tested the hypothesis that each had the same impact on price determination. Using a likelihood ratio test, the corresponding test statistic was 1.45. 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 did not reject the null hypothesis and concluded that private stock and public stock have similar effects (as maintained in the specification (3a)-(3b)).

[7] This choice of m = 9 was found to be robust to the variance specification (3b).

[8] 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.

[9] The dominant root is real and equal to 0.985. The next roots are complex conjugates: they are $0.677 \pm 0.579\, i$, with a modulus of 0.891. They imply cyclical patterns.

[10] The early 1980's was also a period where government butter stocks increased significantly, as the support price program prevented any decrease in butter prices. This generated a high cost to the Treasury.