Economics Bulletin

Volume 31, Issue 1

Are Fruit and Vegetable Prices Non-linear Stationary? Evidence from Smooth Transition Autoregressive Models

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Abstract

Over the last decade, there has been a growing interest in investigating agricultural commodity prices. We apply two more powerful smooth transition autoregressive models of the non-linear unit-root test - namely, the ESTAR model of Kapetanios et al. [Journal of Econometrics (2003)] and the LSTAR model of Leybourne, et a . [Journal of Time Series Analysis (1998)] - with a view to investigating non-linear stationarity for the retail prices of 8 major kinds of fruit and 18 major kinds of vegetable in Taiwan. The empirical evidence clearly finds that the Kapetanios et al. model provides solid, substantive evidence in favor of a non-linear mean-reverting adjustment for the individual price of 4 kinds of fruit and 5 kinds of vegetable. However, when we employ the Leybourne et al. model, we find that any such similar evidence of non-linear stationarity is considerably weaker. Finally, compared with the traditional linear unit root tests, it is important to note here that, all in all, the non-linear unit root tests do indeed provide much more evidence of the stationarity, albeit to varying degrees. This paper offers some policy implications.

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Citation: Jhih-Hong Zeng and Chun-ping Chang and Chien-chiang Lee, (2011) "Are Fruit and Vegetable Prices Non-linear Stationary? Evidence from Smooth Transition Autoregressive Models", *Economics Bulletin*, Vol. 31 no.1 pp. 189-207.
Submitted: Feb 26 2010. **Published:** January 09, 2011.

1. Introduction

With regard to Taiwan's food consumption patterns, fruits and vegetables definitely make up the largest share of the most frequently-consumed foods. For related policies of the local agriculture administration organization, securing stability over fruit and vegetable prices is obviously an important policy target. This paper proposes to examine whether or not the real price series of fruits and vegetables contain a unit root (random walk) with non-linear dynamic adjustments. We believe it is a worthwhile question, because everyone needs to take a close link between agricultural commodity prices and the real economy, no matter if they are governmental organizations or citizens. In this way, they are deeper statistical indicators provided by Taiwan's Agriculture and Food Agency which demonstrate that for major agricultural products, the production values of fruits and vegetables are the highest among them. We also find that fruits have the highest value at 123.3 kilograms, closely followed by vegetables at 104.3 kilograms when we consult Taiwan's per capita per year food consumption in 2005.[1] Therefore, whether or not the statistics are related to either production or consumption, it reveals that fruits and vegetables have prominent positions in Taiwan's agricultural industry.

It is important to note that there are few studies on the stationarity properties of agricultural commodity prices which allow for the possible presence of non-linearities in data. Performing a stationarity test on the fruit and vegetable price series is an important analytical foundation for the pricing of agricultural products because not only can it contribute to distinguishing the inherent characteristics pertaining to price variations, but it can also be used as a benchmark on which the government can mediate uncertainties concerning the prices of agricultural products. This is due to understanding stationary agricultural commodity prices which imply that price series are either trends or mean reverting.

There is a fact that the non-linear unit root test models and, in particular, the smooth transition autoregressive (STAR) models have not been extensively used to examine agricultural commodity price adjustments in similar issues. Our specific purposes and contributions of this paper are as follows: we first use two more powerful approaches of the non-linear unit root test - i.e., the exponential smooth transition autoregressive (hereafter ESTAR) model of Kapetanios *et al.* (2003; hereafter KSS) and the logistic smooth transition autoregressive (hereafter LSTAR) model of Leybourne *et al.* (1998; hereafter LNV) - to examine the non-linear stationarity of the prices of 8 major fruits and 18 major vegetables in Taiwan. If the price series follow a STAR process, then the conventional Augmented Dickey-Fuller (Dickey and Fuller, 1979; ADF) tests based on a linear model will be specified incorrectly and suffer a power loss in detecting the hypothesis of a unit root (Michael et al., 1997). If the price series of fruits and vegetables are mean reverting (trend stationary), then it follows that the price series will return to its trend path over time and this may offer useful information for analysts when they predict the future behavior as well as the evolution of the prices by extrapolating the information based on historical records. If the data are erroneously

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[1] We show the per capita food consumption of Asian countries in 2005 and the value of Taiwan's major crop products in 2003-2005; see Tables A1 and A2 of Appendix. From Table A1, we find that fruits and vegetables share the most weight for value of Taiwan's major crop products of Taiwan. In Table A2, Taiwan is one of the Asian countries which has a relatively higher consumption of these agricultural products.

treated as an integration order 1 (hereafter I(1)) and the causality tests for the price and macroeconomics are applied to the first difference, then a spurious causality will result.

Conventional wisdom mostly works when the fruit-vegetable market is a perfect competitive market, one where information is symmetric and the prices are placed in a free adjustment. However, most countries' fruit-vegetable bargain markets are actually imperfect competitive markets. This is because fruit and vegetable prices are determined by many factors, such as trade costs, supply and demand quantities, agricultural product price interference policies, etc., which do not allow prices to be adjusted at a constant speed and are inclined toward equilibrium. This probably presents that adjustment trends are non-linear. In the price adjustment process, due to exogenous shocks which sometimes cause prices to deviate from equilibrium, structural changes or even breaks may occur. Hence, the assumption that the price adjustment process has a linear relationship at all times may be too restricting.

Previous studies adopting a linear model have proposed empirical evidence that fails to reject the unit-root null in the agricultural commodity prices. Ahmadi-Esfahani (2006) investigated the pricing efficiency in a number of major wholesale food markets in Beijing, Nanjing, Shanghai, and Shenzhen over the period of 1993 to 1999. The results of the ADF unit-root test indicate that the prices of fruits, vegetables, beans, grains, and meat have an integration order 1. Moreover, using the traditional ADF test, Apergis and Rezitis (2003) found that the hypothesis in which the consumer price index of food products contains a unit root cannot be rejected.

It is interesting to note that the issue as to whether or not the prices of agricultural products have non-linear adjustment characteristics has been the subject of extensive research and examination in recent papers. To cite one example, Goodwin and Piggott (2001) delved into the non-linear relationship between the price of American corn and that of soybeans. Along the same line, Abdulai (2000) focused on the non-linear adjustment of the wholesale price of Ghana corn, and Abdulai (2002) concentrated on the non-linear adjustment of the price of pork in Switzerland. Holt and Craig (2006) applied a STAR framework with technical changes and explored that the hog–corn cycle exhibits non-linear features and time-varying parameters. Lee et al. (2006) and Chen and Lee (2008) investigated the dynamic behavior of Taiwanese hog wholesale prices and revealed that non-linearity in hog wholesaler prices exists and that there were structural changes in the hog wholesale markets which they investigated. However, when an evaluation of a non-linear model like those above was carried out, the stationarity of a series became the core of the issue, and an examination method using a traditional linear framework - for example the ADF, the PP (Phillips and Perron, 1988) and the KPSS (Kwiatkowski *et al*., 1992) unit-root testing procedures - must still be followed. The above method of a unit-root testing procedure generates estimates from a non-linear model, but uses a linear model to test the stationary characteristics of the series. In this case, the problems with the use of both models are twofold: model inconsistency and low testing power.

Non-linear unit root tests actually have already been extensively applied to unit-root tests of macroeconomic series - for example, in the level of the application of the KSS (2003) test, Chortareas *et al.* (2002) analyzed the real exchange rate stationary of the G7, while Liew *et al.*

(2004) determined whether the Asian real exchange rates had non-linear stationarity. Wu and Lee (2008) also adopted the KSS method to test the non-linear stationarity of real exchange rates in which they emphasized both the real bilateral exchange rates and the real effective exchange rates. On the application of the LNV (1998) method, Harvey and Mills (2002) analyzed a number of time series that have appeared to undergo two smooth transitions in the linear trend, and they applied the LNV tests to two such series - the average global temperature and the U.S. consumer price index. Sollis (2005) applied the LNV test to focus on deterministic trend-breaks in the quarterly real exchange rate for 20 countries against the US dollar. However, the application of a non-linear approach to price stationarity for agricultural products was rare at the present time.

The remainder of this paper is organized as follows. The next section presents the non-linear unit root test methods - namely the KSS (2003) and the LNV (1998) tests. The third section discusses the non-linear stationarity of the prices in Taiwan and states the empirical findings. The fourth section provides implications and policy suggestions. The final section presents the conclusions.

2. Methodology

2.1 The KSS (2003) test

Kapetanios *et al.* (2003) considered a specific exponential smooth transition autoregressive process as follows:

$$y_t = \beta y_{t-1} + \gamma y_{t-1}\Phi_E(\theta; y_{t-d}) + \varepsilon_t, \quad t = 1,...,T; \quad d \geq 1, \tag{1}$$

where y_t refers to the real retail price series of fruits or vegetables; $\varepsilon_t \sim iid(0,\sigma^2)$; $d \in (1,2,...)$ is a lag parameter; β and γ are unknown parameters; y_t is a mean zero stochastic process and the de-meaned series of interest; and y_{t-d} is a transition variable. In accordance with the literature on the ESTAR model, the transition function that we adopt here is in its exponential form:

$$\Phi_E(\theta; y_{t-d}) = 1 - \exp(-\theta y_{t-d}^2) \,. \tag{2}$$

Term θ is known as the mean-reversion and transition parameter of the ESTAR model that governs the speed of transition. The exponential transition function is bound between zero and 1, giving it the following properties:

$$\Phi_E(0) = 0; \lim_{x\to\pm\infty} \Phi_E(x) = 1, \tag{3}$$

based on the above exponential transition characteristics, we are able to plot the U-shape symmetrically around zero, as shown in Figure A1 of the Appendix. The astounding ESTAR model describes the trends of the series with a middle regime and an outer regime or the adjustment of a regime. It is based on the adjustment of the middle regime ($\Phi_E(\theta; y_{t-d}) = 1$) and that of the outer regime ($\Phi_E(\theta; y_{t-d}) = 0$), which describes the trends of the series when the transition series is in either a positive or a negative regime and when they have the same characteristic symmetric dynamics of the trend.

Using equation (2) in equation (1), we obtain an exponential ESTAR model:

$$y_t = \beta y_{t-1} + \gamma y_{t-1}\left[1 - \exp\left(-\theta y_{t-d}^2\right)\right] + \varepsilon_t\,, \tag{4}$$

which can conveniently be re-parameterized as:

$$\Delta y_t = \phi y_{t-1} + \gamma y_{t-1}[1 - \exp(-\theta y^2{}_{t-d})] + \varepsilon_t\,, \tag{5}$$

where the coefficient on the one period lagged series is $\phi = \beta - 1$. In the context of our model, this should imply that while $\phi \geq 0$ is possible, we must restrict $-2 < \gamma < 0$ and $\phi + \gamma < 0$ for the process to be globally stationary. Following Balke and Fomby (1997), we impose $\phi = 0$ and d = 1 which gives our specific ESTAR model (5):

$$\Delta y_t = \gamma y_{t-1}[1 - \exp(-\theta y^2{}_{t-1})] + \varepsilon_t \quad . \tag{6}$$

We might expect that the standard linear ADF test is not very powerful when the true process is stationary, but non-linear. Thus, we develop a testing framework for this context. In equation (6), when $\theta = 0$, then y_t follows a non-linear trend. Our test focuses directly on the specific parameter θ which is zero under the null, but positive under the alternative. Hence, we test: $H_0 : \theta = 0,$ against the alternative: $H_1 : \theta > 0.$ However, directly testing the null hypothesis is not feasible since γ is unidentified under the null.

To overcome this problem, KSS (2003) added the lagged differences of the dependent variables and corrected for plausible serially-correlated errors. KSS re-parameterized equation (6) based on the Taylor series approximation to obtain:

$$\Delta y_t = \delta y_{t-1}^3 + \sum_{j=1}^{p} \rho_j \Delta y_{t-j} + error, \tag{7}$$

and as KSS pointed out, we can use conventional *t*-statistics for equation (7). The null hypothesis to be tested is $\delta = 0$ against the alternative $\delta < 0$, and thus:

$$NLADF = \frac{\hat{\delta}}{s.e.\left(\hat{\delta}\right)}. \tag{8}$$

KSS showed that the NLADF statistics of the parameter of interest (that is, δ) do not have an asymptotic normal distribution, and thus we must resort to simulations for the asymptotic critical values. However, Chortareas and Kapetanios (2004) found that the differences between the finite sample and the asymptotic critical values are negligible. We therefore apply the asymptotic critical values of KSS in the empirical analysis.

2.2 The LNV (1998) test

Leybourne, *et al.* (1998) and Kapetanios *et al.* (2003) are both smooth-transition models, but the difference lies in the LNV's adoption of the logic transition function which is used in the structural change series with the time item. Leybourne *et al.* (1998) tested the I(1) null against three possible alternatives. We now turn to three specific tests with different stationarity. In Model A, y_t is stationary around a changing mean; in Model B, y_t is similar, but allows for a fixed-slope term (β_1); and in Model C, y_t is stationary around a changing mean and a changing slope, with both changes occurring simultaneously and at the same speed of transition. The three generalized logistic smooth transition regression models are represented as:

Model A： $y_t = \alpha_1 + \alpha_2 S_t(\gamma,\tau) + v_t$; (9)

Model B： $y_t = \alpha_1 + \beta_1 t + \alpha_2 S_t(\gamma,\tau) + v_t$; and (10)

Model C： $y_t = \alpha_1 + \beta_1 t + \alpha_2 S_t(\gamma,\tau) + \beta_2 t S_t(\gamma,\tau) + v_t$, (11)

where $v_t \sim iid(0,\sigma^2)$ is a zero-mean *I*(0) process, and $S_t(\gamma,\tau)$ is a logistic smooth transition function. The form is as follows:

$$S_t(\gamma,\tau) = [1 + \exp\{-\gamma(t - \tau T)\}]^{-1}, \qquad \gamma > 0 \tag{12}$$

where T is the sample size; parameter τ determines the timing of the transition mid-point; parameter γ determines the speed of the transition; and *t* is the transition parameter for the trend item. Given that $\gamma > 0$ and is a monotonically increasing function that is bound between zero and 1, its characteristics are as follows:

$$S_{-\infty}(\gamma,\tau) = 0; S_{+\infty}(\gamma,\tau) = 1; S_{\tau T}(\gamma,\tau) = 0.5. \tag{13}$$

We plot the logic transition function, as illustrated in Figure A2 of Appendix. It is clearly observed that this monotonically increasing function in a transition process has the characteristics of a smooth transition. This model describes the trends of the series with the upper and lower regimes or regime adjustments. In other words, in light of $S_t(\gamma,\tau)$=1 and $S_t(\gamma,\tau)$=0 in the upper and lower regimes of the model, we are able to describe the trends of the variables when $S_t(\gamma,\tau)$ at 0 and 1. Therefore, the dynamic trends of the transfer to the upper regime and that to the lower regime are not same. Simply stated, it is an asymmetric adjustment trend.

Proceeding with our tests involves following two steps. First, we fit one of the models, either A, B, or C, through the non-linear least-squares method, which minimizes the sum of squared v_t. Denoting $\hat{v}_t$ as the residual from this first-step regression, we next fit the ADF auxiliary regression and yield the model as follows:

$$\Delta\hat{v}_t = \rho\hat{v}_{t-1} + \sum_{i=1}^{k}\delta_i\Delta\hat{v}_{t-i} + \eta_t. \tag{14}$$

The test statistic employed by equation (14) is the *t*-ratio associated with the least-squares method to estimate ρ. The LNV matches the three models and provides the s_α, $s_{\alpha(\beta)}$, and $s_{\alpha\beta}$ statistics for Models A, B, and C, respectively. In addition, LNV duplicated the critical value of the Monte Carlo simulations and carried out the non-linear stationary test on the macroeconomic series and determined that the power and size of all surpass that of the traditional ADF test. Thus, we use the KSS and LNV methods and their respective asymptotic critical values to perform our empirical analysis.

2.3 The comparison between linear and non-linear unit root tests

Before comparing the difference, we see, for example, the graphs of linear and non-linear models. In Figure A3, we compared both functions. One is a linear function with slope 0.5 and the other is a nonlinear function following equation (4), where we set $\beta = \gamma = \theta = 0.5$ and $d = 1$. In contrast to the linear function with a constant slope, the slope of the non-linear function is conditional on the value of x (here, we set the lagged-term y_{t-1} to be x).

In econometrics, the stationary process indicates that the mean and variance of the time-series data do not change over time or position. Therefore, the nonlinearity of data could cause an incorrect integrated order and a series of biased estimations. For example, if the linear methods cannot reject the existence of the unit root but the non-linear unit root test can, then it would be obstructed in predicting due to the presence of the unit root. Furthermore, in predicting the future price, the past price information is always with a high correlation and is usually a key factor of estimations or predictions. Compared with a constant correlation between current and past prices in linear models, the non-linear models represent that the correlation is conditional in the magnitude of past prices. For example, if the past price (x) is higher, then its influence (as to the slope) on the current price is much larger. In addition, when the unit root can be rejected with a non-linear test but the linear tests cannot, it represents that an application of simple non-linear models would yield more correct predictions. It should be noticed that the non-linear models have infinite kinds of types. Here, we merely adopt powerful methods to examine them. But, the differentials between both non-linear unit root tests have been represented in models as they should be with regard to the characteristics of each kind of fruits and vegetables.

3. The Data

We took all the retail prices of the fruit and vegetable series that we used in the study from the *AREMOS Economic-statistic Databank*, Taiwan's regional agricultural statistics database, created jointly with the Taiwan Ministry of Education. We selected these samples because these fruits and vegetables were most commonly consumed by Taiwanese residents. All variables are expressed in real terms to overcome the possibility that the results reflect fluctuations in the inflation rate. Based on the availability of consistent data, we selected relatively nominal retail prices of eight kinds of fruit and 18 kinds of vegetables in Taiwanese cities, and we transformed them into the real price series by using the consumer price index of fruit and vegetables in the base year 2001. We targeted the different categories of fruits and vegetables and conducted empirical research. Among them, the eight major kinds of fruit we studied consisted of bananas, pineapples, liu-chengs, watermelons, melons, guavas, papayas and grapes, while the 18 major kinds of vegetables consisted of radishes, carrots, potatoes, onions, leeks, ginger, cabbage, Chinese mustard, celery, cauliflower, wax gourds, rag gourds, bitter gourds, bottle gourds, eggplants, tomatoes, green peppers, and kidney beans. Our monthly data for the fruit prices covered the period from 1981M1 to 2003M12, whereas those for the vegetable prices covered the period from 1982M1 to 2003M12.

Tables 1 and 2 list the summary statistics of the prices of each of the fruits and vegetables. Based on the size of the standard deviations, we note that the price of grapes show the highest fluctuations, while those of pineapples have the lowest. In terms of excess fare, the maximum is for grapes at NT$267.63 per kilogram, a sharp contrast to pineapples which is the minimum at NT$43.73 per kilogram. Turning to vegetables, the prices of bitter gourds fluctuate the most, and those of carrots the least. The maximum excess fare is for ginger at NT$183.86 per kilogram, while the minimum is for leeks at NT$47.93 per kilogram.

4. Empirical Results

It is worth noting that the selection of the lag length is an essential component in the unit-root test process, we adopted the rules of the Modified Akaike Information Criterion (hereafter, MAIC) to select the lag orders. In addition, we follow Hayashi (2000) when setting up the maximum lag-length in the model. In order to provide a benchmark for the non-linear unit root tests, we begin by using the linear ADF tests which include both an intercept and a trend. Tables 3-6 summarize the unit-root test results.[2] Among them, Tables 3 and 4 show the ADF and NLADF unit-root test results for fruit and vegetable prices, respectively. Tables 5 and 6 provide the results from the LNV (1998) test immediately, where NLADF stands for the KSS test statistics, and $s_{\alpha\beta}$ is the LNV approach. LNV applies their test statistic $s_{\alpha\beta}$ to a classic set of U.S. macroeconomic time series, as first analyzed by Nelson and Plosser (1982). This test corresponds to our most general transitions in the trends based on Model C.

Because KSS and LNV both used the ADF for a comparison foundation of test power, we also report our conventional ADF test statistics, with the lag-order decided by the MAIC. Table 3 shows that under the 5% level of significance, the ADF test rejects the null of the unit root in three cases - for bananas, liu-chengs, and guavas. While Table 4 reveals that only the price of radishes is a stationary series, indicating that the standard linear ADF test fails to demonstrate its stationary test power. This is probably because fruit and vegetable prices represent a non-linear adjustment series. The above method causes non-linear model estimates, but uses the linear model to test the stationary characteristics of the series. It produces problems of model inconsistency and weak test power.

We next to turn to the non-linear stationary test. The results from both the NLADF unit-root tests were able to reject the unit root in the case of four fruits (bananas, liu-chengs, guavas, and grapes) and five vegetables (radishes, carrots, potatoes, onions, and bottle gourds) at the 5% level of significance. This implies that when the choice of the optimal number of lags occurs, more fruit and vegetable prices are mean-reverting. It is interesting to note that compared with the results of the standard ADF tests which indicate stationarity for only a few prices, the NLADF test results show much more evidence of stationarity.

The LNV (1998) and KSS (2003) methods both belong to the smooth transition autoregressive model, but as mentioned earlier, the difference lies in LNV's adoption of the logic transition function. It is used in the structural change series with the time item. Aside from this, the KSS of the ESTAR model is based on the adjustments of the middle and outer regimes to describe the symmetric dynamic trends, but compared with the KSS method, the LNV is based on asymmetric adjustments. Therefore, the dynamic patterns of transfer to the upper and lower regimes are not the same. In view of the two differences above, we can expect that by considering the dynamic

[2] Since the critical values of unit-root are from the approximating distribution, it needs a stricter significance level for the smaller samples in this paper. Thus, we adopt 5% as the significance level. Moreover, the linear ADF unit root test is sensitive to sample size.

adjustment and transition methods of the series that we can examine more evidence of non-linear stationary characteristics of fruit and vegetable prices. Hence, we further carry on the unit-root test with the LNV of the LSTAR model.

We adopt the non-linear method to estimate the model with the LNV parameters, including $\hat{\alpha}_i$, $\hat{\beta}_i$, $\hat{\gamma}$ and $\hat{\tau}$ in equation (11), where the initial values of the parameters are given in LNV (1998) and revised repeatedly to result in an estimated convergence. Tables 5 and 6 list the estimated parameters $\hat{\tau}$ and $\hat{\gamma}$ of the logic transition function, and clearly the results all match the theoretical requirements with $\gamma > 0$ and $0 < \tau < 1$. Determining v_t from the residuals of this first-step regression, we next fit the ADF auxiliary regression with equation (14). The unit root of the null hypothesis is rejected at the 5% significance level for the three fruits-liu-chengs, melons and guavas, as the $s_{\alpha\beta}$ test in Table 5. Moreover, Table 6 shows that only the price of radishes is in a stationary series. Compared with the KSS test results, we find that from the asymmetry dynamic adjustment of the LNV test, the evidence is weaker than the series of fruit and vegetable prices which are stationary in the non-linear unit root test. This finding demonstrates that the conclusions drawn from the linear and non-linear unit root tests may be drastically different. In other words, the KSS (2003) and LNV (1998) tests seem to be more powerful with regard to the different directions of the deviations from the null hypothesis, as expected. Dumas (1992) argued that under certain restrictive conditions such as identical transaction costs and homogeneity of agents, the mean-reverting behavior tends to smooth the transition between regimes. Thus, the KSS (2003) rejects a few more price series as being non-stationary. Based on our findings, while the most important responsibility of a government body is to maintain price stabilization of these agricultural goods, the government usually faces high costs for carrying out intervening actions. In addition, current agricultural-prices for the Taiwanese government is how to precisely keep track of the price behavior. This is also becoming a most beneficial facility for policymakers.

5. Implications and Policy Suggestions

There are several reasons to believe a priori that a STAR framework may prove fruitful. One might expect prices to be stationary, because of market dynamics, time lags between price changes, or supply/demand imbalances. As fruits and vegetables are affected by changes in supply and demand, prices are typically characterized by striking fluctuations, or more to the point, such factors as natural environmental conditions, weather, seasonal factors, and natural disasters, among others, have a strong impact in this regard. Aside from these factors, fresh produce is not easily stored or transported. This causes further fluctuations in the supply, and consequently, in the prices.[3] Since January 2002, when Taiwan was granted membership in the World Trade Organization (WTO), its agricultural product market has been opened up to a significant quantity of imports which have also

3 To stabilize vegetable production and sales, the government principally focuses on leafy vegetables, root vegetables, and flower-fruit vegetables, among others, and in doing so, it is guided by such common projects as “stabilizing summer supply and demand for vegetables” and “establishing vegetable production and sales regulations in the winter” to name but two, see Lee et al. (2006).

had a direct impact on the prices of domestic agricultural products. However, excessive variations in the prices of agricultural products oftentimes make farmers' decision-making policies with respect to the type of production they should engage in difficult at best. It goes without saying that these decisions carry important meaning and certainly influence management type, farming income, not to mention the usage of particular agricultural resources.

It is obvious that there exists a larger share of non-stationary series in fruit and vegetable prices in our empirical results, even though we have added them with non-linear unit root tests. Generally speaking, the non-stationary time series-price represents that the market is efficient. Moreover, it indicates that the exogenous shocks would induce permanent effects on non-stationary prices. Particularly in Taiwan, the government has exercised frequent intervention for the fruit and vegetable markets. However, over-intervention would cause fruit and vegetable prices to have permanent variation which would make them more difficult to forecast.

Non-stationarity is a leading sign of an efficient market and the inability in forecasting for the prices. There are many possible factors causing the non-stationary process (random walk). For example, regime shifting is one of the possible factors. In Taiwan, most of the fruit and vegetable prices have no constant trends or variation due to the impact of uncertain factors such as weather and several substitutes and complements of fruits and vegetables in each season. However we could not make sure whether such factors would cause the regime shifting and non-stationarity (it needs more detailed examinations). Therefore, fruit and vegetable prices in Taiwan are difficult to forecast except for some kinds of fruits and vegetables in our results.

On the other hand, our results represent that the number of stationary series for utilizing non-linear unit root tests is greater than the number for the linear method. That is most stationary prices of fruits and vegetables are approaching nonlinear models. Intuitively, as stated in Section 2.3, the adjustment of current fruit and vegetable prices according to the information of past prices should not be constant as we use the autoregressive models to estimate and predict. For example, if the past prices of fruits or vegetables were higher (it may higher than the expected one) then the adjustment of the current price would be higher than the common one.

Several important policy implications emerge from the results of the non-linear unit-root tests. First, the non-linear stationarity series suggest that the stabilization or regulation policies of agricultural commodity prices may not be over-implemented in Taiwan for the price level of four fruit prices and five vegetable prices under the current study. Second, if the data were erroneously treated as non-stationary and the causality tests for agricultural commodity prices and macroeconomics were applied to the first difference, a spurious causality would result in the estimation. Third, evidence in favor of the stationarity hypothesis is found, implying that agricultural commodity prices are not characterized by the efficient market hypothesis. This reason offers the presence of profitable arbitrage opportunities among prices. Fourth, for forecasting purposes, the fact that prices exhibit a random walk means that it is not possible to forecast future movements in prices based on past behavior. Thus, by substituting linear models with nonlinear ones, we could possibly forecast the prices of fruits and vegetables. Fifth, the fact that prices exhibit a random walk suggests that other macroeconomic variables that are linked to prices via flow-on effects such as output will potentially inherit non-stationarity in prices that spread to the real economy. Sixth and finally, when we conduct research into prices in the future - for example, when the relationship between agricultural commodity prices and macroeconomics is estimated - we should take a non-linear dynamic adjustment into account as they can reflect the true current status.

On the other hand, there are differentials in the empirical results of the non-linear unit root tests-KSS (2003) and LNV (1998). We obtain more evidence of nonlinear stationarities in fruit and vegetable prices when using the KSS method. Here we spot two main differentials in the two methods. In the KSS method, a mean-reversion is observed but the LNV method is used in the structural changes series with the time item. In the KSS method, the parameter of a symmetric adjustment is used but the LNV method is used with an asymmetric adjustment trend as shown in Figures A1 and A2. Our empirical results then exhibit that some prices of fruits and vegetables are of non-linear stationarities with the mean-reversion process in Taiwan. Of course, not all kinds of fruit or vegetable prices must be in such a process. However, it is important to consider that nonlinear stationarity will result in biased predictions even though spurious estimations.

6. Conclusions

This paper applies two powerful non-linear unit root tests to examine eight major kinds of fruits and 18 major kinds of vegetables in Taiwan. Although most fruit and vegetable prices are non-stationary, we still find that some kinds of fruits and vegetables are stationary with non-linear methods but non-stationary with linear methods which were especially true for the KSS (2003) method. Such results would follow by some implications and policy suggestions (discussed in Section 5). The crucial contribution of this research is, for the first time, to investigate the non-linear features in the prices of fruits and vegetables and to provide plausible interpretations and suggestions for policy making in Taiwan's agricultural product market. This will contribute to the established governmental policy. Whether or not the prices of agricultural products have non-linear adjustment characteristics has been extensively examined in recent papers. However, after evaluating the non-linear model as we did above, the stationarity of the series is a basic requirement. This carries on the valuation that the non-linear model must still follow an examination method through the use of traditional linear models - for example, the ADF, PP, and KPSS for linear unit root testing procedures. The above method generates the non-linear model estimates, but due to the use of linear models to test for the stationary characteristics of the series, both are expected to have problems of model inconsistency and test power inadequacy.

To fill this gap, this paper has employed two non-linear exponential smooth transition autoregressive models: the ESTAR model of KSS (2003) and the LSTAR model of LNV (1998). Our purpose is to examine the stationarity of fruit and vegetable real retail price series in Taiwan. The empirical evidence convincingly reveals that in the KSS model, there are 4 fruit prices and 5 vegetable prices which show non-linear stationarity. However, when we adopt the LNV model, we find the evidence to be weaker for fruit and vegetable prices with non-linear stationarity. Finally, compared with the traditional ADF test, we see that by using the non-linear unit–root test, we are able to obtain more evidence that fruit and vegetable prices are stationary. Therefore, the stationary findings of fruit and vegetable prices not only contribute to distinguishing the innate characteristics of price variations, but they also can be used as a benchmark for the government to resolve problems associated with the price of agricultural products.

Acknowledgements

An earlier version of this paper was presented at the 2005 REST-KAEA International Conference on Agricultural Economics and Resource, National Taiwan University, Taiwan. The authors are also grateful to the National Science Council of Taiwan for financial support through grant NSC 94-2415-H-005-003. The usual disclaimer applies.

Appendix

Table A1. Value of Taiwan's Major Crop Products in 2003-2005

Year	Paddy Rice	Coarse Grain	Special Crops	**Fruit**	**Vegetables**	Mildew	Ornamental Plants
2003	28.34	7.53	7.57	**55.23**	**34.64**	2.77	11.17
2004	27.51	7.77	7.11	**63.65**	**40.72**	2.98	12.52
2005	28.13	7.45	7.42	**62.30**	**42.62**	2.85	11.82

Note: Units in billions.

Table A2. Food Consumption Per Capita of Asian Countries in 2005

Country	Taiwan	China	India	Indonesia	Japan	South Korea	Malaysia	Philippines	Saudi Arabia	Thailand
Cereals	91.5	189.6	200.0	245.9	173.4	217.6	169.6	198.0	260.6	47.0
Starchy roots	21.7	75.9	22.6	65.9	38.4	19.2	22.5	27.7	17.5	124.9
Sugar and honey	26.3	77.7	195.0	133.9	119.3	125.2	378.7	226.9	47.8	301.3
Pulse and oilseeds	27.3	74.6	61.1	109.1	73.7	90.7	92.6	30.2	76.0	114.4
Fruits	**123.3**	**58.1**	**34.7**	**54.7**	**58.4**	**65.1**	**57.2**	**97.5**	**98.1**	**76.3**
Vegetables	**104.3**	**292.4**	**65.8**	**30.8**	**130.7**	**253.6**	**48.6**	**61.8**	**116.7**	**32.1**
Meat	77.1	60.8	5.1	12.6	36.6	38.3	48.2	32.6	54.2	32.2
Eggs	16.8	18.3	1.8	3.7	18.7	11.1	11.9	6.7	4.6	9.1
Milk	47.4	18.0	66.4	7.5	75.5	39.9	43.0	18.0	107.2	28.1
Fish and seafood	29.9	34.0	4.8	21.3	67.0	61.9	59.8	31.7	6.8	31.1
Animal fats	4.5	0.0	0.2	0.3	0.5	1.8	0.6	2.3	0.3	0.6
Others	21.8	0.8	3.5	3.6	7.4	2.6	4.9	1.9	5.6	1.8

Note: Units in kilograms.

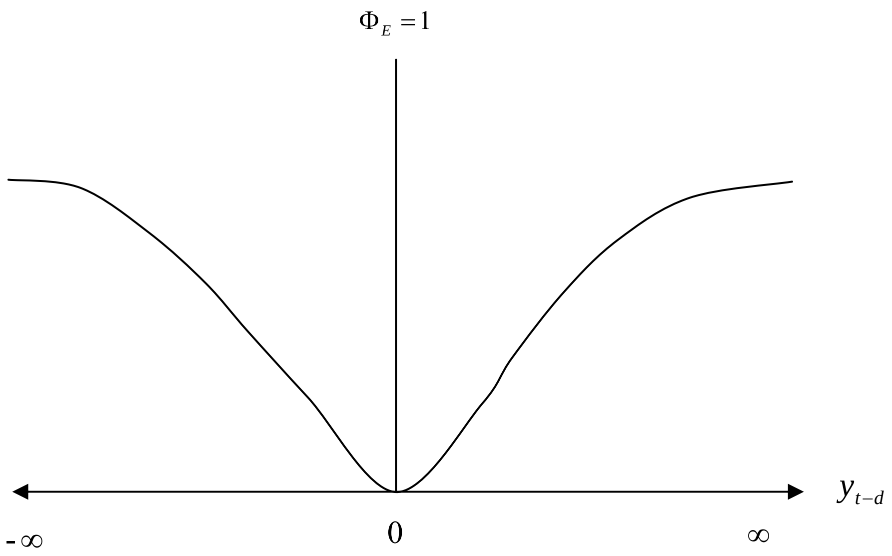

Figure A1. Plot of the Kapetanios *et al.* (2003) Exponential Transition Function

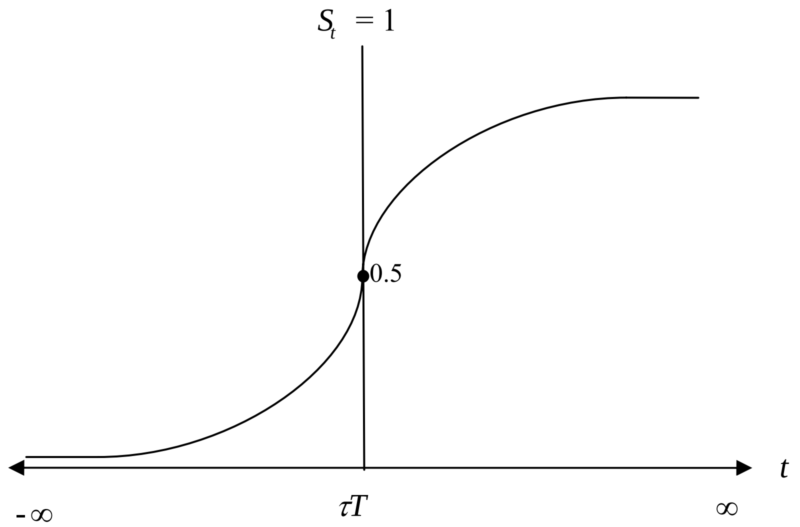

Figure A2. Plot of the Leybourne, *et al.* (1998) Logic Transition Function

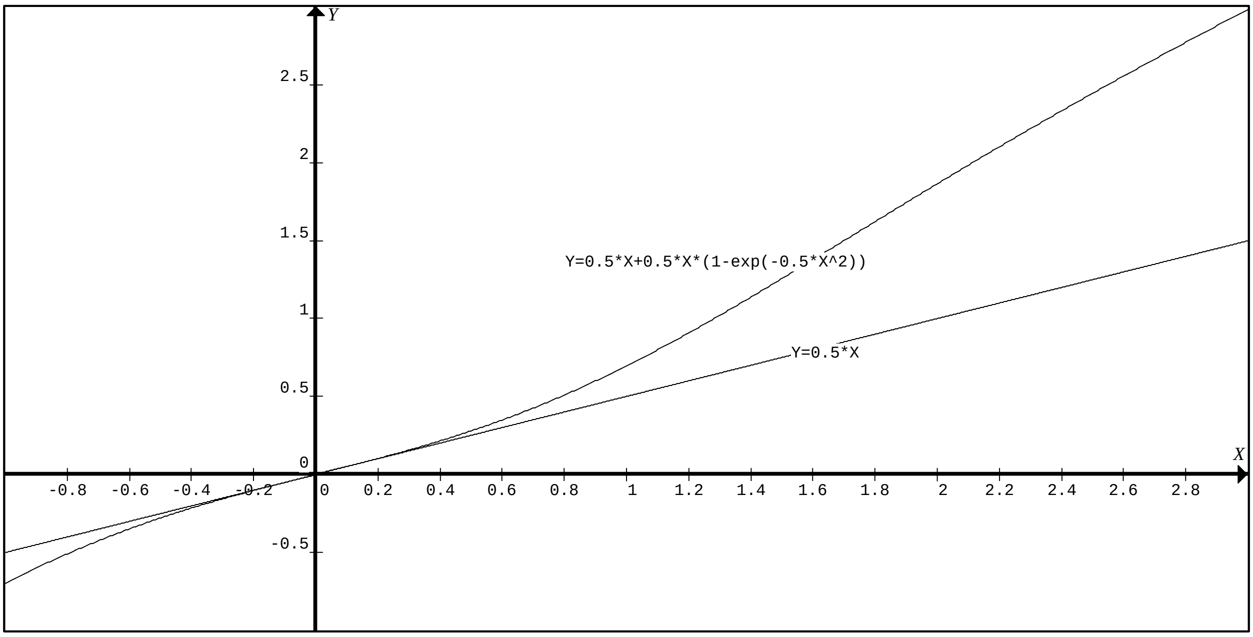

Figure A3. Graphs of Linear and Nonlinear Functions

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Table 1. Summary Statistics of Fruit Prices

	Mean	Maximum	Minimum	Std. Dev.
Bananas	50.58	107.18	30.85	13.26
Pineapples	55.19	78.83	35.10	9.75
Liu-chengs	60.41	128.38	2.42	19.24
Watermelons	53.74	115.50	26.52	17.19
Melons	70.27	158.57	40.09	16.96
Guavas	54.69	96.17	28.36	16.20
Papayas	71.10	171.80	35.49	25.15
Grapes	129.65	346.90	79.27	29.07

Table 2. Summary Statistics of Vegetable Prices

	Mean	Maximum	Minimum	Std. Dev.
Radishes	40.77	83.67	21.51	10.66
Carrots	38.19	89.04	21.08	8.47
Potatoes	50.90	127.31	25.57	14.60
Onions	44.99	111.69	26.65	12.36
Leeks	50.79	81.08	33.15	8.58
Ginger	93.70	228.25	44.39	29.12
Cabbage	44.03	88.42	21.29	12.95
Chinese Mustard	49.41	89.51	29.01	10.73
Celery	70.52	118.50	40.69	16.60
Cauliflower	76.56	176.26	34.59	25.11
Wax Gourds	35.46	107.97	18.46	11.69
Rag Gourds	54.84	109.14	29.73	13.43
Bitter Gourds	80.75	193.48	44.56	25.55
Bottle Gourds	43.49	84.36	27.84	9.63
Eggplants	60.27	95.85	41.63	10.86
Tomatoes	65.53	140.17	32.22	15.92
Green Peppers	83.78	186.26	45.96	23.95
Kidney Beans	89.86	126.13	62.79	10.59

Table 3. Unit Root Test Results for Fruit Prices - the ADF and NLADF tests

Variables	Lags	ADF	NLADF
Bananas	5	-3.739**	-3.921**
Pineapples	9	-2.117	-1.047
Liu-chengs	0	-4.082**	-6.928**
Watermelons	14	-1.977	-2.782
Melons	12	-1.798	-2.272
Guavas	0	-7.756**	-5.693**
Papayas	10	-2.545	-2.300
Grapes	11	-2.192	-4.748**

Notes: The 5% asymptotic null critical value τ_τ (with a constant and linear trend) for the ADF test is -3.43, (MacKinnon, 1991), and that for the NLADF test is -3.40 (KSS, Table 1, Case 3). We select the lag orders following the MAIC by Ng and Perron (2001). **denotes significance at the 5% level.

Table 4. Unit Root Test Results for Vegetable Prices - the ADF and NLADF tests

Variables	lags	ADF	NLADF
Radishes	0	-7.528**	-8.816**
Carrots	10	-3.239	-5.979**
Potatoes	9	-3.249	-5.026**
Onions	10	-3.397	-3.967**
Leeks	10	-3.256	-1.565
Ginger	9	-2.696	0.734
Cabbage	14	-2.198	-0.140
Chinese Mustard	14	-2.188	-1.965
Celery	13	-2.602	-2.540
Cauliflower	13	-1.916	0.092
Wax Gourds	10	-3.205	-2.745
Rag Gourds	14	-2.094	-0.904
Bitter Gourds	11	-2.737	-0.151
Bottle Gourds	12	-2.318	-3.880**
Eggplants	11	-2.752	-2.381
Tomatoes	14	-2.752	-2.235
Green Peppers	14	-2.242	-1.165
Kidney Beans	11	-3.402	-1.635

Note: See Table 3.

Table 5. Unit Root Test Results for Fruit Prices - the LNV Model based on Model C

Variables	$s_{\alpha\beta}$	$\hat{\gamma}$	$\hat{\tau}$
Bananas	-3.760	0.956	0.490
Pineapples	-2.227	1.522	0.506
Liu-chengs	-5.059**	0.091	0.357
Watermelons	-3.848	1.801	0.490
Melons	-4.903**	0.067	0.651
Guavas	-7.877**	1.667	0.484
Papayas	-2.823	1.697	0.478
Grapes	-3.542	0.633	0.494

Notes: The significance at the 5% level of $s_{\alpha\beta}$ is -4.867 (LNV, Table 1); $\hat{\gamma}$ determines the speed of the transition; and $\hat{\tau}$ determines the timing of the transition midpoint. We select the lag orders following the MAIC by Ng and Perron (2001). ** denotes significance at the 5% level.

Table 6. Unit Root Test Results for Vegetable Prices - the LNV Test based on Model C

Variables	$s_{\alpha\beta}$	$\hat{\gamma}$	$\hat{\tau}$
Radishes	-7.642**	1.477	0.441
Carrots	-4.621	0.082	0.444
Potatoes	-3.691	0.797	0.439
Onions	-3.597	1.297	0.491
Leeks	-3.602	1.171	0.435
Ginger	-3.039	2.494	0.483
Cabbage	-2.504	3.734	0.345
Chinese Mustard	-3.317	0.128	0.461
Celery	-3.168	1.622	0.534
Cauliflower	-1.945	2.048	0.265
Wax Gourds	-3.320	1.587	0.426
Rag Gourds	-3.222	1.717	0.424
Bitter Gourds	-3.547	0.054	0.349
Bottle Gourds	-2.887	1.561	0.421
Eggplants	-4.137	1.870	0.412
Tomatoes	-3.524	1.974	0.405
Green Peppers	-3.380	0.181	0.464
Kidney Beans	-4.376	0.246	0.420

Note: See Table 5.