(First draft, Comments welcomed)

Dynamics of a market with market participants switching their expectation formation functions: an empirical application to the U.S. hog market

SaangJoon Baak
Graduate School of International Relations
International University of Japan
Yamato-machi, Minami Uonuma-gun
Niigata, 949-7277 Japan

Email: sbaak@iuj.ac.jp
Phone: 81-257-79-1510
Fax: 81-257-79-1187

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ABSTRACT

This paper explores the dynamics of the U.S. hog market with three different dynamic models that are distinguished only by their assumptions with regard to market participants' expectations of future prices. The first model assumes that all the producers in the market have rational expectations. The second model assumes that a constant fraction of the producers have static expectations. The third model, the main focus of this paper, assumes producers choose either rational expectations or static expectations every year based on the past performance of the two different types of expectations. Empirical tests such as log-likelihood ratio type specification tests of GMM estimations and one-step ahead forecasts indicate the third model best captures the movements of the price and quantity data in the hog market, even though the value added by the third model over the second is not great. Simulation experiments illustrate that the market will reach a steady state in the framework of the first and the second model if external shocks are zero. In contrast, in the framework of the third model the market never reaches a steady state but generates cyclical movements of economic variables. Artificially increasing the intensity of choice higher than that suggested by empirical tests, makes the dynamics of the market described by the third model become chaotic.

JEL Classification: C61, C62, E32, E37

Keywords: Heterogeneous expectations, Bounded rationality, Economic cycles, Non-linear dynamics, Chaos

1. Introduction

This paper investigates the dynamics of the U.S. hog market with three different dynamic models that are distinguished only by their assumptions with regard to market participants' expectations of future prices. Specifically, the paper aims to determine which model best captures the movements of the actual data of the market. Subsequently, the dynamics of the market are explored using the three models, with particular attention given to the best model.

Model 1 has the scheme of typical linear quadratic investment (or, inventory) decision models such as in Sargent (1987, Ch. 14) and in West (1993). Producers intend to maximize their present and future stream of profits by optimal investment. They are fully rational in the sense that their expectations are equivalent to mathematical expectations. Jarvis (1974) and Rosen et al. (1994) employ this kind of model to explain the dynamics of cattle markets.

The other two models (Model 2 and Model 3) presented in this paper are identical to Model 1 with the exception of the assumption regarding the expectations of the future prices. Model 2 assumes that a constant fraction of the producers have static expectations. Therefore, there exist two different types of economic agents, rational and boundedly rational ones, in the market. Using this type of model, Baak (1999, 2000) and Chavas (1999, 2000) estimated the fractions of boundedly rational economic agents in agricultural markets and reported the fractions are significantly different from zero.

In the meantime, Model 3 assumes, following Brock and Hommes (1997), a producer choose either a rational or a static expectations formation function every year based on the observed relative performances of the two different expectations formation functions. Since the choices of the producers are not homogeneous, the fraction of boundedly rational economic agents can fluctuate between zero and one.

Empirical tests such as log-likelihood ratio type specification tests of GMM estimations and one-step ahead forecasts indicate Model 3 best captures the movements of the price and quantity data in the hog market. Therefore, the main focus of this paper is given to this model, as the title of this paper implies. It should be noted, however, that the value added by Model 3 over Model 2 is not great, while Model 2 performs significantly better than model 1.

Simulation experiments illustrate that the market will reach a steady state in the framework of Model 1 and Model 2 if external shocks are zero. In contrast, in the framework of Model 3 the market never reaches a steady state but generates cyclical movements of economic variables, indicating the market is inherently volatile. This finding implies that recent economic models predicting inherent non-linear dynamics may be useful instruments to explain the real economy. Simulations by the three models do not illustrate any chaotic dynamics. However, it may be informative to report that the dynamics of the market described by Model 3 became chaotic when the intensity of choice was increased higher than that suggested by empirical tests.

2. Models

The three models presented in the paper adopt the framework of renewable resources management models. Similar models are employed in Jarvis (1974), Chavas and Klemme (1986), Rosen et al. (1994), Chavas (1999, 2000), Baak (1999, 2000). They can be regarded as conventional linear dynamic investment (or, inventory) decision models applied to the agricultural sector. (See Lucas and Prescott (1971), Lucas (1981), Sargent (1987, Ch. 14), and West (1993) for the typical format of the investment (or, inventory) decision model.)

Model 1 in the present paper assumes that all the producers in the market are fully rational. Model 2 assumes, following Chavas (1999, 2000) and Baak (1999, 2000), that a constant fraction of the producers have static expectations. It implies that there are two different types of producers in the market with regard to expectations of future prices. In addition, neither rational nor boundedly rational producers change their expectation formation functions over time.

Following Brock and Hommes (1997), Model 3 assumes that producers choose either rational expectations or static expectations every year based on the past performance of the two different types of expectations. Since their decisions are not homogeneous, the fraction of boundedly rational economic agents can be any number between zero and one in the model.

With the exception of the assumption regarding the expectations of future prices, the three models are identical. The basic framework of the models is presented next. Their differences are discussed at the end of this section.

Production technology

The final output of the hog industry at time t is the sum of surviving adult animals from the previous year and the one-year old animals joining the adult stock.

$$y_t = (1-d)k_{t-1} + (1-d)gx_{t-1}$$

(1)

$$x_{t-1} = gk_{t-1}$$

(2)

where y_t is the final output, k_{t-1} is the adult stock at time $t-1$, x_{t-1} is the pig crop at time $t-1$, d is the natural death rate, and g is the birth (fertility) rate per adult animal. Piglets can join the breeding stock at 8 months. Therefore, it is reasonable to assume that they become adults after one period. The death rate is assumed to be non-negative and the birth rate, positive. [1]

The final output is either marketed or held as an investment for future production (that is held for breeding). Therefore, in this industry, the amount of capital (breeding) stock at time t equals the amount of investment at time t.

$$y_t = i_t + c_t$$

(3)

$$k_t = i_t$$

(4)

where i_t is investment, c_t consumption (or sales), and k_t breeding (capital) stock at time t. Since all young males are sold (or slaughtered) at maturity, the final output held for future production is all female. Therefore, even though y_t and gk_{t-1} contains males and females, k_t contains only females.

Two types of producers

As already mentioned, the first model of this paper assumes only one type of producers. In contrast, the second and the third model contain two types of producers who have different expectations for the future price of hog. One type (a rational producer) is assumed to fully

[1] Refer to Chavas (1999) fora more detailed explanation on the production technology of hog markets.

understand the market dynamics. He knows that the market price of hog is endogenously determined in the market. He purposefully acquires and uses all available information including the existence of his boundedly rational counterpart to predict future prices. This implies his prediction will be the same as that of the model.

The other type (a boundedly rational producer) is assumed to treat the hog price as an exogenous variable whose value is determined independently from market dynamics. Like in Grandmont (1994), Nerlove and Fornari (1998), and Hommes and Sorger (1998), a boundedly rational producer is assumed to formulate his hog price expectations based on time series observations. In particular, since the detrended hog price data do not fit to any AR process and look like random walks to naked eyes, a boundedly rational producer in this paper is assumed to have static expectations. That is, he holds Ezekiel's (1938) cobweb expectation. With the exception of his approach to hog prices, however, this type is assumed to be as rational as his rational counterpart. The only difference between the two types of hog producers is in their predictions of future hog prices.

Objective function

The integral sum of all producers in the present model is assumed to be unity without loss of generality. The fraction of boundedly rational producers at time t is denoted by n_t. By definition, n_t is between zero and one. The goal of a producer, whether rational or boundedly rational, is assumed to be to maximize the expected present discounted value of current and future profits over an infinite horizon of time. Specifically, the objective function a producer intends to maximize is the following:

$$\max_{i_{j,t}} E_{j,0}\left\{\sum_{t=1}^{\infty} b^{t}\left[p_t c_{j,t} - r_h h_t\left(k_{j,t}+x_{j,t}\right) - \frac{y_c}{2}c_{j,t}^2 - \frac{y_0}{2}k_{j,t}^2\right]\right\} \qquad (5)$$

$$\text{s.t.} \quad c_{j,t} = (1-d)k_{j,t-1} + gk_{j,t-1} - i_{j,t}$$

$$k_{j,t} = i_{j,t}$$

$$x_{j,t} = gk_{j,t}$$

where p_t is the market price of an adult animal and $r_h h_t$ is the one-period holding costs for a breeding animal and a piglet. The quadratic term $\frac{y_0}{2}k_t^2$ captures the increasing costs of holding adult animals and $\frac{y_c}{2}c_t^2$ captures the increasing costs of preparing for slaughter. The discount factor b is assumed to be positive yet less than one. The parameters y_c and y_0 are assumed to be positive.

The subscript *j* in the endogenous state variables c, k, and the control variable i denotes that the variables are associated with a type *j* (*j*=1 or 2) producer. Hereafter, subscripts 1 and 2 represent rational and boundedly rational economic agents, respectively. For example, $c_{1,t}$ and $c_{2,t}$ are the quantities supplied by a rational and boundedly rational producer, respectively.

The holding costs $\{h_t\}_{t=0}^{\infty}$ are exogenous state variables, while the price stream $\{p_t\}_{t=0}^{\infty}$ is determined by the competitive market equilibrium.

Demand

The demand for hogs is assumed to be a linear function of the market price as in other agricultural articles such as Rosen et al (1994) and Chavas (1999).

$$c_t = a_0 - a_1 p_t + r_d d_t + e_t^d, \quad \text{where } a_0 > 0, a_1 > 0 \tag{6}$$

where d_t is a demand shifter and e_t^d is a white noise. It is typical to assume a linear market demand function in investment (or, inventory) decision models.[2]

Euler equation

Even though the two types of producers have the same objective function, they have different Euler equations because they predict future hog prices differently. The Euler equation of a rational producer is

[2] See West (1993)

$$E_t\begin{bmatrix} -p_t + y_c c_{1,t} - r_h h_t(1+g_0 g) \\ + b\left(p_{t+1}(1-d+g) - y_c c_{1,t+1}(1-d+g)\right) \end{bmatrix} = 0$$

(7)

On the other hand, the Euler equation of a boundedly rational producer is

$$E_t\begin{bmatrix} -p_t + y_c c_{2,t} - r_h h_t(1+g_0 g) \\ + b\left(-y_c c_{2,t+1}(1-d+g)\right) + E_{2,t}\left(bp_{t+1}(1-d+g)\right) \end{bmatrix} = 0$$

(8)

where $E_{2,t}$ denotes the expectations operator of a boundedly rational producer. As mentioned earlier, he has static expectations. Therefore, $E_{2,t}(p_{t+i}) = p_{t-1}$ where i = 0, 1, 2 …

The aggregate (market) Euler equation (9) in the following is obtained by the summation of equation (7) and (8) after multiplying the fraction of rational producers, $(1-n_t)$, to equation (7) and the fraction of boundedly rational producers, n_t, to equation (8).

$$E_t\begin{bmatrix} -(1-n_t)p_t + y_c c_{1,t} - r_h h_t(1+g_0 g) \\ + b\left((1-n_t)p_{t+1}(1-d+g) - y_c c_{1,t+1}(1-d+g)\right) \\ -n_t p_t + n_t b(1-d+g)p_{t-1} \end{bmatrix} = 0$$

(9)

Aggregating the constraints in the objective function (5) generates the following law of motions:

$$c_t = (1-d)k_{t-1} + gk_{t-1} - k_t$$

(10)

$$x_t = gk_t$$

(11)

Then, the market as a whole is described by the aggregate Euler equation (9), the law of motions (10) and (11), and the demand function (6). The deep parameters of the model can be estimated with these six equations using GMM. The model can take three different forms according to the assumption with regard to n_t.

Model 1

Model 1 assumes that producers are homogeneous and fully rational. Therefore, the fraction of boundedly rational agents, n_t, is zero.

Model 2

Model 2 assumes that a fraction of producers possess static expectations and that the fraction is constant. Therefore, the fraction of boundedly rational agents, n_t, is a constant number between zero and one. That is, $n_t = \bar{n}$.

Model 3

Following Brock and Hommes (1997), model 3 assumes that producers choose either rational expectations or static expectations every year based on the past performance of the two different types of expectations. Since their decision is not homogeneous, the fraction of boundedly rational economic agents (n_t) in any year can be any number between zero and one in the model. For simplicity and empirical tractability, it is assumed that the functional form of n_t is not known to the economic agents in the market but that its value is observed by rational producers in the beginning of time *t*. The fraction, n_t, is treated like a time-varying parameter.

3. Data

The data set contains annual observations for the pig crop (x_t), the number consumed (c_t), the breeding stock (k_t), the price of an adult animal (p_t), the corn price, and the beef cattle price for the U.S. during the period 1945~1997. The corn price and the beef cattle price are used as proxies for the holding cost (h_t) and the demand shifter (d_t), respectively. The data are detrended by the Hodrick-Prescott filter. In each of the six time series, the difference between the first observations in the original and in the detrended time series was added to the detrended time series to make the detrended quantity and price data take on positive values. Some information on the data is presented in Table 1.

Adding to those data above, we need the proxy for n_t to perform GMM estimations with model 3. In the paper of Brock and Hommes (1997),

$$n_t = \frac{e(bp_{2,t-1})}{e(bp_{1,t-1}) + e(bp_{2,t-1})}$$

where b = intensity of choice, $\mathbf{p}_{1,t-1}$ = performance measure of rational expectations at time t-1, and $\mathbf{p}_{2,t-1}$ = performance measure of boundedly rational expectations at time t-1. In the present paper, a simplified version of the above function is used to generate the data for n_t, for empirical tractability.

$$n_t = \frac{e(b\mathbf{p}_{2,t-1})}{1 + e(b\mathbf{p}_{2,t-1})}$$

where $\mathbf{p}_{2,t-1} = aF_{t-1} + bF_{t-2} + c$, $F_{t-1} = -|p_{t-1} - p_{t-2}|$, $F_{t-2} = -|p_{t-2} - p_{t-3}|$ and the parameters a, b and c are positive values. This function implies that the fraction of boundedly rational agents will decrease if their prediction errors increase. A number of series were computed for n_t by changing the values of the parameters a, b and c.[3] When $a = 0.2$, $b = 0.2$ and $c = 0.6$, model 3 generated the best results.[4] In this case the average of n_t is 0.39.

[3] $a = 0.1,\ 0.2,\ \cdots,\ 1.0;\ b = 0.0,\ 0.2,\ \cdots,\ 1.0;\ c = 0.0,\ 0.2,\ \cdots,\ 1.0$. Parameters a and b are similar to the intensity of choice in Brock and Hommes (1997).

[4] The estimation results of model 3 with these parameter values are reported in the following section.

4. Empirical test results

Some parameter values are set a priori to reduce the number of parameters to be estimated. The discount factor (b) is assumed to be 0.96 following AHMS and Baak (1999). Agricultural literature usually does not contain quadratic cost terms as in Rosen et al (1994) and Chavas (1999). These terms are included in the present paper to make the objective function linear quadratic. Therefore, the coefficients of the quadratic cost terms are assumed to be close to zero: $y_0 = 0.0001$, $y_c = 0.0001$.[5] The remaining parameters are estimated by GMM.[6]

All the parameter values are significantly estimated by the three models at the 5% significance level, and turn out to be within reasonable boundaries. In Table 2, the estimates and the standard errors of the parameters are reported.

<u>Comparison of model 1 and 2</u>

The specification test of the two models using log-likelihood ratio type statistic, suggested in Ogaki (1993), supports model 2 (a heterogeneous expectations model) over model 1 (a rational expectations model). The null and the alternative hypothesis of this test are:

$$H_0: \quad n = 0$$
$$H_A: \quad n \geq 0$$

The statistic is $T(J_T(\hat{q}) - J_t(\tilde{q}))$, where $J_T(\hat{q})$ is the minimized value of the GMM function of the unrestricted model (model 2) and $J_T(\tilde{q})$ is the minimized value of the GMM function of the restricted model (model 1). The degree of freedom, r, is the number of restrictions. In model 1, the restriction is $n = 0$ and thus the number of restrictions is 1. Since the parameter space is restricted under the alternative hypothesis, the test statistic is distributed as a mixture of Chi-squared distributions.[7] Specifically, under the null hypothesis, the distribution of the

[5] Anderson et al. (1996) also make the same assumption when they estimate the model of Rosen et al (1994).
[6] The Hansen-Heaton-Ogaki GMM codes explained in Ogaki (1993) were used for the estimation. The method of Andrews (1991) was adopted to compute the covariance matrix.
[7] See Gourieroux, Holly and Monfort (1982) and Andrews (1996).

statistic is $\frac{1}{2} c^2(0) + \frac{1}{2} c^2(1)$. The critical value at the 5% significance level is 2.71. The test statistic exceeds the critical value, rejecting the null hypothesis of homogeneous full rationality.

Comparison of model 2 and 3

Since the difference between model 2 and model 3 does not lie with parameter value restrictions, the specification test above cannot be used to compare the two models. Instead, one-step ahead forecasts of the hog price are done to compare the performance of the two models. Table 3 shows model 3 generates lower mean-squared errors than model 2, even though the difference is not so big as that between model 1 and model 2.

5. Simulation experiments

Artificial data of the breeding stock (k_t) are generated using the three models and their estimated parameter values. In these simulation experiments, exogenous variables are fixed to be constant to see the dynamics of the hog market when external shocks are zero.

As shown in Figures 1 through 3, the market reaches a steady state in the framework of model 1 and 2, though model 2 requires a much longer period to get to a steady state than model 1. It implies these two models attribute the volatility of the market mainly to external shock. In contrast, the market never reaches a steady state in the framework of model 3. Instead it generates cycles in the long run. If we increase the values of a and/or b, model 3 even generates chaotic dynamics. Figure 4 illustrates this.

6. Conclusion

This paper presented three investment decision models of the U.S. hog market that are distinguished only by their assumptions with regard to market participants' expectations of future prices. Then, it investigated which model best captures the movements of the actual data of the market. Model 3, in which market participants switch their expectation formation functions, better explained the dynamics of the U.S. hog data than the models in which the fraction of boundedly rational economic agents is zero (model 1) or constant (model 2).

Simulation experiments performed by model 1 and 2 illustrated that the economy would reach a steady state, if external shocks were zero. In contrast, Model 3 generated cycles without any external shocks, implying cycles are inherent phenomena in the hog market. However, the intensity of choice was not big enough to create chaos in the market.

This paper finds the possibility that economic models incorporating heterogeneous expectations may explain our economy better than conventional rational expectations models. In addition, this implies that our economy may be inherently unstable. The simulation experiments in section 5 illustrated that economic cycles can be persistent even without any external shocks.

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[Table 1] Sample Means and Standard Deviations

Variable	Mean	Std. Dev.
x_t	85.337	5.808
k_t	13.067	0.663
c_t	72.994	4.993
p_t	30.870	2.802
h_t	24.341	1.972
d_t	26.933	3.128

[Table 2] GMM Estimation Results

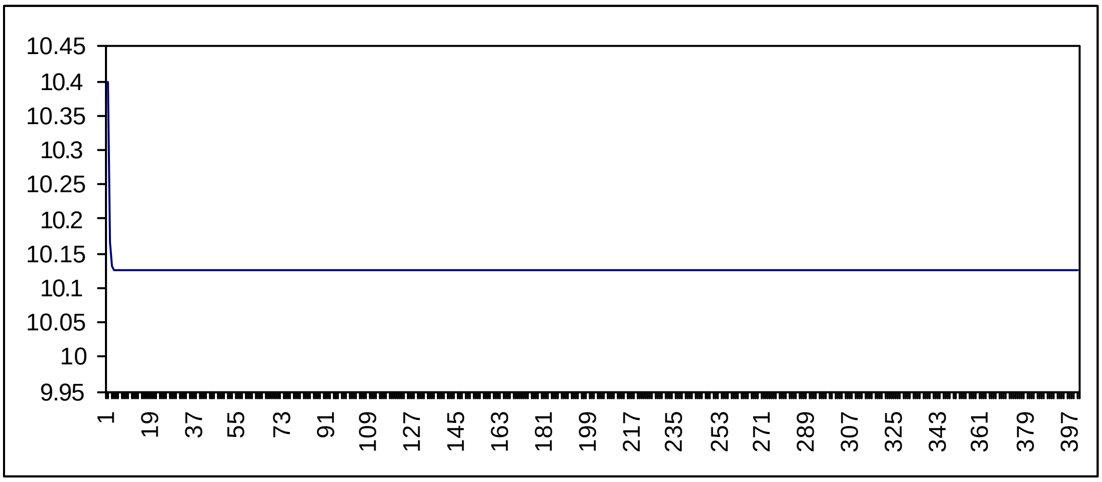
Parameters	Model 1 ($n_t = 0$)		Model 2 ($n_t = \bar{n}$)		Model 3 (a =0.2, b =0.2, c =0.6)	
	Estimates	Std. error	Estimates	Std. error	Estimates	Std. error
a_0	108.571	2.881	107.838	2.766	110.912	2.879
a_1	1.849	0.051	1.850	0.048	1.893	0.049
g	6.556	0.028	6.536	0.030	6.520	0.023
d	0.125	0.002	0.120	0.003	0.119	0.002
r_h	0.884	0.008	0.899	0.006	0.892	0.005
r_d	0.798	0.063	0.830	0.056	0.763	0.055
$\bar{n}$	n.a.	n.a.	0.528	0.027	n.a.	n.a.
J_T [1)]	18.197		16.819		16.338	

1) The minimized value of the GMM function

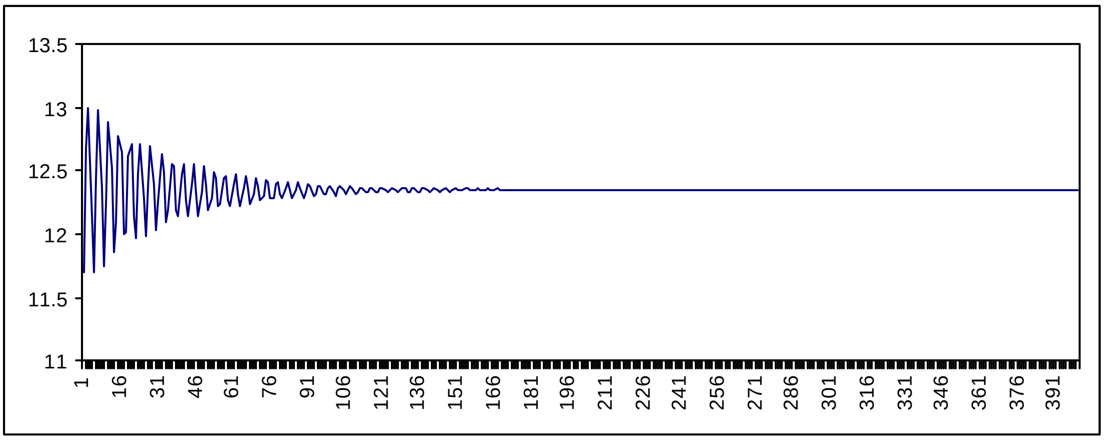
[Table 3] MSE of one-step ahead forecasts of the hog price

Model 1	Model 2	Model 3
7.550	4.605	4.475

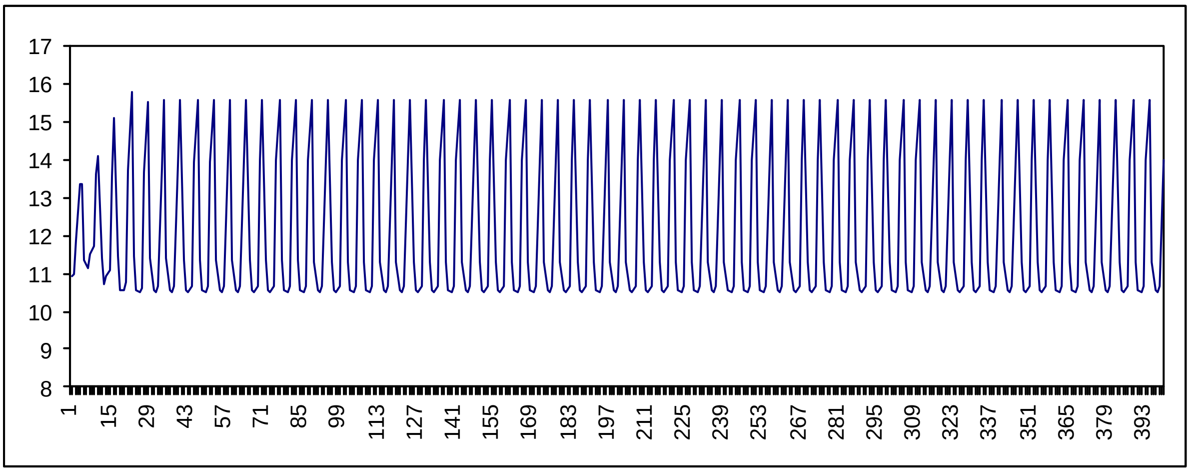
[Figure 1] Simulated data by model 1



[Figure 2] Simulated data by model 2



[Figure 3] Simulated data by model 3 (a=0.2; b=0.2; c=0.6)



[Figure 4] Simulated data by model 3 (a=0.6; b=0.2; c=0.6)