Model Reference Adaptive Pollution Control Analysis in Global Environment

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Abstract

As for the pollution control in global environment, it is necessary to clarify in more detail the structural relationship among the climatic activities in atmosphere, the economic activities on land and the ecological activities in marine, and to investigate a number of paths which converge to the reference model (sustainable world) and the adaptation process of system and its stability by using Model Reference Adaptive Control System.

In this paper, we therefore attempt to examine in more detail inter-field repercussion placing the emphasis mainly on the two-fields case. More specifically, we are interested in gaining the insights into the balance of inter-field repercussion by Hermite Inverse Matrix Method which shows the total effects of inter-field propagation. Furthermore, for the achievement of model reference pollution reduction, we investigate a path converging to the reference model, the adaptive processes of system and its stability by making use of Model Reference Adaptive Input-Output Model and Model Reference Adaptive Ecological Model. These models are to make it clear how the actual world converges to the sustainable world once the reference world is established.

1. Introduction, Global Environment

It is already clear that the environment nowadays is violating the sustainability because of drastic and widespread human impacts on the global environment. The developed countries have been gradually getting economically disadvantaged by the poisonous waste cumulated in air, water and on land. The poisonous waste products begin to harm crops, forests, fisheries, livestock and also humanbeing, particularly the newborn.

In the developing countries, poverty causes a widespread and steady degradation of the

productive capacity of woodlands, rangelands and agricultural soils, caused by inappropriate deforestation, overstocking of pastures, overharvesting of cropland and woodland as well as overexploitation of fragile and other marginal lands. The struggle to obtain enough water, food, wood fuel and shelter for daily survival from a dwindling resource-base may result in public unrest, even civil conflict and the migration of environmental refugees, and in extreme cases, it can bring about destabilization of the country. In addition to these national and regional problems, we face the global climate changes such as Acidification, Ozone depletion and the Greenhouse effect caused by high waste of developed countries. The global environmental problems are likely to have quite serious impacts which in turn may lead to the disadvantage of all nations worldwide in the coming decades.

Acidification

The problem of acid precipitation from burning of fossil fuels is the single largest environment problem connected to energy today. Large areas in the world, especially in Europe and North America are affected with the results of widespread forest damage and decline of forest agricultural productivity. Many countries receive much more acid precipitation from other countries than what they discharge for themselves. The problem of air pollution and acidification which was rather a regional problem a few decades ago is now rapidly becoming a global problem.

Deforestation

Deforestation and associated desertification, partly due to the very complicated and poorly understood social ecological processes, are primarily caused by expanded agriculture and associated overgrazing, industrial needs, large-scale export oriented forestry and an ever-increasing demand for energy by growing city population.

Climatic change any Greenhouse effect

Release of Carbon Dioxide from fossil fuel combustion, deforestation to a certain extent and a number of other gases discharged from certain industrial and biological sources result in a build-up of Greenhouse effect in the atmosphere. This process has the potential to change the Earth's Climate profoundly in the near future. It is expected that if the present trends are to continue the level of Carbon Dioxide in the middle of the next century will be doubled with the level before the Industrial Revolution. This may come in effect to globally increase the mean temperature some value between 1.5 to 4.5 centigrads and to rise the sea-levels by some between 20-100 centimeters. Various and large areas in the world would be vulnerable to the rise in the sea level. Flooding will certainly damage the shallow countries such as Bangladesh, Nile Delta, Netherlands island nations such as the Seychelles and the Maldives, and other several estuaries and harbours.

It is possible to state several reasonable definitions of sustainable world in the technological sense, if not necessarily possible in institutional or policy sense yet. The sustainable world

futures we intend to seek for are those in which the adequate supply of commodities and/or services to satisfy people's want is guaranteed for centuries, whereas the resultant environmental consequences do not put an unacceptable burden on the society. It is necessary to investigate a number of paths which converges to the reference model (sustainable world) and the adaptation process of system and its stability with the aid of Model Reference Adaptive System which is to clarify how the actual world would approach to the sustainable world, provided that the reference world is established.

2. Hermits Inverse Matrix Method

This chapter is devoted to a slightly more detailed examination of the structure of interrelational repercussion among the climatic activities in atmosphere, the economic activities on land and the ecological activities in marine. Specifically, we are concerned with gaining on insights into the balance of interrelational repercussion by using Hermite Inverse Matrix Method (Yamamura (1973))

This matrix method is basically represented by an Hermite Matrix with the Inverse Matrix which shows the total effects of interrelational propagation.

2.1 Two field model

If we focus our attention on just the tow major divisions, the economic activities on land and the ecological activities in marine, there are four major sets of cells in the flow, or coefficient, table to be considered. Fox example, for the coefficient table A is as followes ;

$$A = \begin{bmatrix} A^{LL} & A^{LM} \\ A^{ML} & A^{MM} \end{bmatrix} \quad (1)$$

where,

A^{LL} : the coefficients indicating the flows of commodities from land sources to meet the requirements of activities on land.

A^{LM} : the coefficients indicating the flows of commodities from land sources to meet the requirements of the activities in marine.

A^{ML} : the coefficients indicating the flows of commodities from marine sources to meet the requirements of activities on land.

A^{MM} : the coefficients indicating the flows of commodities from marine sources to meet the requirements of activities in marine.

We define the notations of partitioned matrices as follows :

$B^L = [I - A^{LL}]^{-1}$: total direct and indirect production coefficients on land.

$B^M = [I - A^{MM}]^{-1}$: total direct and indirect production coefficient in marine.

$$C^{ML} = A^{ML} \cdot B^L \quad (2)$$

C^{ML} : total input coefficients from marine sources to meet production of activities on land.

$$C^{LM} = A^{LM} \cdot B^M \quad (3)$$

C^{LM} can be interpreted as C^{ML} by permuting the activities on land and those in marine each other.

$$D^{LM} = B^L \cdot A^{LM} \quad (4)$$

D^{LM} : total production coefficient from land sources to meet the total requirement of activities in marine.

$$D^{ML} = B^M \cdot A^{ML} \quad (5)$$

D^{ML} can be interpreted as D^{LM} by permuting the activities on land those in marine each other.

$$G^{LM} = [I - D^{LM} \cdot D^{ML}]^{-1} \cdot B^L \quad (6)$$

$$G^{ML} = [I - D^{ML} \cdot D^{LM}]^{-1} \cdot B^M \quad (7)$$

G^{LM} : total effect coefficients on land.

G^{ML} : total effect coefficients in marine.

The ecological activities in marine are defined as the activities based on the materials for economic activities and the impact resources arising from the pollution of economic activities on land. With respect to a more detailed work. readers may refer to Isard (1972).

2.2 Three field model

Assuming just the three major divisions, land, marine and atmosphere, there are nine major sets of cells in the flow, or coefficient, table to be considered. For example, the coefficient table A is as follows :

$$A = \begin{bmatrix} A^{LL} & A^{LM} & A^{LP} \\ A^{ML} & A^{MM} & A^{MP} \\ A^{PL} & A^{PM} & A^{PP} \end{bmatrix} \quad (8)$$

where,

A^{LL} : the coefficients indicating the flows of commodities from land sources to meet the requirement of activities on land.

A^{LM} : the coefficients indicating the flows of commodities from land source to meet the requirements of activities in marine.

A^{LP} : the coefficients indicating the flows of commodities from land sources to meet the requirement of activities in atmosphere.

A^{MM} : the coefficients indicating the flows of commodities from marine sources to meet the requirements of activities in marine.

A^{MP} : the coefficients indicating the flow of commodities from marine sources to meet the requirements of activities in atmosphere.

A^{PP} : the coefficients indicating the flow of commodities from atmosphere sources to meet the requirements of activities in atmosphere.

A^{ML} , A^{PL} and A^{PM} indicates shipments in the opposite direction.

This matrix shows the total effects of interrelational propagation focus on the three major divisions, land, marine and atmosphere.

$$B = (I - A)^{-1} = \begin{bmatrix} E^{L(M)}(I + \bar{D}^{LP} \cdot E^{P(L,M)} \cdot \bar{D}^{PL} \cdot E^{L(M)})B^L \\ E^{M(L)}(\bar{D}^{ML} + \bar{D}^{MP} \cdot E^{P(L,M)} \cdot \bar{D}^{PL} \cdot E^{L(M)})B^L \\ E^{P(L,M)} \cdot \bar{D}^{PL} \cdot E^{L(M)} \cdot B^L \\ E^{L(M)}(D^{LM} + \bar{D}^{LP} \cdot E^{P(L,M)} \cdot \bar{D}^{PM} \cdot E^{M(L)})B^M \\ E^{M(L)}(I + \bar{D}^{MP} \cdot E^{P(L,M)} \cdot \bar{D}^{PM} \cdot E^{M(L)})B^M \\ E^{P(L,M)} \cdot \bar{D}^{PM} \cdot E^{M(L)} \cdot B^M \\ E^{L(M)} \cdot \bar{D}^{LP} \cdot E^{P(L,M)} \cdot B^P \\ E^{M(L)} \cdot \bar{D}^{MP} \cdot E^{P(L,M)} \cdot B^P \\ E^{P(L,M)} \cdot B^P \end{bmatrix} \quad (9)$$

where,

$$\begin{aligned} E^{L(M)} &= (I - D^{MP} \cdot D^{PM})^{-1} & \bar{D}^{LP} &= D^{LP} + D^{LM}D^{MP} \\ E^{M(P)} &= (I - D^{MP} \cdot D^{PM}) & \bar{D}^{MP} &= D^{MP} + D^{ML}D^{LP} \\ E^{P(L,M)} &= (I - D^{PL} \cdot D^{LP})^{-1} & \bar{D}^{ML} &= D^{ML} + D^{MP}D^{PL} \end{aligned} \quad (10)$$

$$D^{PL} = B^L \begin{bmatrix} A^{LP} \\ A^{MP} \end{bmatrix} = \begin{bmatrix} E^{L(M)}(D^{LP} + D^{LM} \cdot D^{MP}) \\ E^{M(L)}(D^{ML} \cdot D^{LP} + D^{MP}) \end{bmatrix}$$

$$D^{LP} = B^P [A^{SL} \quad A^{PM}] = [D^{PL} \quad D^{PM}]$$

$E^{M(L)}$, $E^{P(M)}$, $\bar{D}^{PL}$, $\bar{D}^{PM}$ and $\bar{D}^{LM}$ indicates shipments in the opposite direction.

2.3 Two region model of Harmite Inverse Matrix Model

Denote the two regions by superscripts I and II. Then A^{II} (A^{III}) represent the matrix of interregional input-output coefficients in region I, (II). Also $A^{I II}$ shows per unit inputs from each sector in region I to each sector in region II, and $A^{II I}$ indicates shipments in the opposite direction.

Thus, letting

$$A = \begin{bmatrix} A^{II} & A^{I II} \\ A^{II I} & A^{II II} \end{bmatrix} \quad (11)$$

A simple calculation yields ;

$$A = \begin{bmatrix} A^{II} & A^{III} \\ A^{II I} & A^{II II} \end{bmatrix} = \begin{bmatrix} A^{II} + A^{II I} & A^{II II} + A^{II III} \\ A^{II I} + A^{II II} & A^{II II} + A^{II III} \end{bmatrix} \quad (12)$$

where

$$A^{KJ} = (A^{KJ} + (A^{JK})')/2, \quad A'^{KJ} = (A^{KJ} - (A^{JK})')/2 \\ K, J = I, II$$

We define the notations of partitioned matrices as follows :

$B^I = [I - A^{II}]^{-1}$: total direct and indirect production coefficients in region I.

$B^{II} = [I - A^{II II}]^{-1}$: total direct and indirect production coefficients in region II.

$$C^{III} = A^{III} \cdot B^I = (A^{III} + A^{III I}) \cdot B^I = A^{III} \cdot B^I = A^{III} \cdot B^I + A^{III I} \cdot B^I$$

C^{III} : total input coefficients from region II necessary to sustain production in region

I.

$C^{III} = A^{III} \cdot B^I$: total average input coefficients from region II necessary to sustain production in region I.

$C^{III} = A^{III} \cdot B^I$: total input variation coefficients from region II necessary to sustain production in region I.

$$C^{III} = A^{III} \cdot B^{II} = (A^{III} + A^{III I}) \cdot B^{II} = A^{III} \cdot B^{II} + A^{III I} \cdot B^{II} \\ C^{III} = A^{III} \cdot B^{II}, \quad C^{III} = A^{III I} \cdot B^{II}$$

The meanings of C^{III} , C^{III} and C^{III} are respectively the same as those of C^{III} , C^{III} and C^{III} mutatas mutandis.

$$D^{III} = B^I \cdot A^{III} = B^I \cdot (A^{III} + A^{III I}) = B^I \cdot A^{III} + B^I \cdot A^{III I}$$

D^{III} : total production coefficients in region I to meet the total requirements of region II.

$D^{III} = B^I \cdot A^{III}$: total average production coefficients in region I to meet the requirements of region II.

$D^{III} = B^I \cdot A^{III}$: total production variation coefficients in region I to meet the requirements of region II.

$$D^{III} = B^{II} \cdot A^{III} = B^{II} \cdot (A^{III} + A^{III I}) = B^{II} \cdot A^{III} + B^{II} \cdot A^{III I}$$

The meaning of D^{III} , D^{III} and D^{III} are respectively the same as those of D^{III} , D^{III} D^{III} mutatas mutandis.

$G^{III} = [I - D^{III} \cdot D^{III}]^{-1} \cdot B^I$: total effect coefficients in region I.

$G^{III} = [I - D^{III} \cdot D^{III}]^{-1} \cdot B^{II}$: total effect coefficients in region II.

It is evident that this model is useful for examining in more detail the structure of an interregional repercussion in the two region case.

3. Model Reference Adaptive Pollution Control Model

For the achievement of model reference pollution reductions, we investigated a path which converges to the reference model and the adaptation processes of system and its stability by using Model Reference Adaptive Input-Output Method.(Yamamura(1983, 1984, 1985) ; Miyata and Yamamura(1990))

This Method is to clarify how the actual field activities would converge to the reference structure when the reference field structure is established.

Model Reference Adaptive Pollution Control Method is composed of two models such as :

Reference model

$$X_m(t+1) = B_m^{-1}(I - A_m + B_m)X_m(t) - B_m^{-1}H(t) \quad (13)$$

Adaptive model

$$X(t+1) = B^{-1}(t+1)(I - A(t) + B(t))X(t) - B^{-1}(t+1)H(t) \quad (14)$$

where,

X_m : n -dim, reference output vector to achieve the model reference pollution reduction

A_m : $n \times n$ reference input coefficient matrix to achieve the model reference pollution reduction

$H(t)$: n -dim, final demand vector to achieve the model reference pollution reduction

$X(t)$: n -dim, real output vector

$A(t)$: $n \times n$, real input coefficient matrix

$B(t)$: $n \times n$, real capital coefficient matrix

The reference model represents a reference growth model to achieve the model, reference pollution reduction, and the adaptive model is a real model which converges asymptotically and stably to the reference output through technological changes whose initial condition is given.

For later use, we rewrite (13) and (14) as follows ; Adaptive model.

Reference model

$$X_m(t+1) = C_m X_m(t) + D_m(t+1)H(t) \quad (15)$$

Adaptive model

$$X(t+1) = C(t+1)X(t) + D(t+1)H(t) \quad (16)$$

where, $C_m = B_m^{-1}(I - A_m + B_m)$

$$D_m = -B_m^{-1}$$

$$C(t+1) = B^{-1}(t+1)(I - A(t) + B(t)) \quad (17)$$

$$D(t+1) = -B^{-1}(t+1)$$

The adaptation that $C(t)$ and $D(t)$ are determined to make $\lim_{t \rightarrow \infty} \|X_m(t) - X(t)\| = 0$ is

equivalent to the asymptotic stability of the error equation mentioned below.

$$\varepsilon(t+1) = C_m \varepsilon(t) + (C_m - C(t+1))X(t) + (D_m - D(t+1))H(t). \quad (18)$$

The adaptation laws are introduced from the next equations.

$$\begin{aligned} C(t+1) &= C(t) + \varepsilon(t+1)H^T(t) \\ D(t+1) &= D(t) + \varepsilon(t+1)H^T(t) \end{aligned} \quad (19)$$

These equation may be written as

$$\begin{aligned} C(t+1) &= C(0) + \sum_{i=0}^t E(i+1)X^T(i) \\ D(t+1) &= D(0) + \sum_{i=0}^t E(i+1)H^T(i) \end{aligned} \quad (20)$$

Namely, the adaptation laws of $C(t)$ and $D(t)$ are determined by the past trend of $\varepsilon(t)$.

However, eqations (20) include $E(t+1)$, therefore, let $\varepsilon(t+1)$ be transformed as follows ;

$$\varepsilon(t+1) = \frac{1}{K(t)} \bar{\varepsilon}(t+1) \quad (21)$$

where,

$$\begin{aligned} K(t) &= 1 + \|X(t)\|^2 + \|H(t)\|^2 \\ \bar{\varepsilon}(t+1) &= X_m(t+1) - C(t)X(t) - D(t)H(t) \end{aligned} \quad (22)$$

If $K(t)$ is getting sufficiently large as $t \rightarrow \infty$, then the below-stated adaptation laws of $C(t)$, $D(t)$ make the error equation asymptotically stable.

$$\begin{aligned} C(t+1) &= C(t) + (I + \Gamma(t))^{-1} Kc \otimes \bar{\varepsilon}(t+1)H^T(t) \\ D(t+1) &= D(t) + (I + \Gamma(t))^{-1} Kd \otimes \bar{\varepsilon}(t+1)H^T(t) \end{aligned} \quad (23)$$

where Kc and Kd are the matrices which have positive elements i, e, $Kc = (Kc_{ij})$, $Kd = (Kd_{ij})$, Kc_{ij} and $Kd_{ij} > 0$, $\otimes$ stands for a matrix operation defined by;

$$\begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \otimes \begin{bmatrix} b_{11} & \cdots & b_{1n} \\ \vdots & & \vdots \\ b_{n1} & \cdots & b_{nn} \end{bmatrix} = \begin{bmatrix} a_{11}b_{11} & \cdots & a_{1n}b_{1n} \\ \vdots & & \vdots \\ a_{n1}b_{n1} & \cdots & a_{nn}b_{nn} \end{bmatrix} \quad (24)$$

and $\Gamma(t)$ represents the following $n \times n$ diagonal matrix.

$$\Gamma(t) = \begin{bmatrix} \sum_{j=1}^n \{kc_{ij}X_j^2(t) + kd_{ij}h_j^2(t)\} & \mathbf{0} \\ \mathbf{0} & \sum_{j=1}^n \{kc_{nj}x_j^2(t) + kd_{nj}h_j^2(t)\} \end{bmatrix} \quad (25)$$

If the sequence $\{H(t)\}_{t=0}^{\infty}$ include sufficient linearly independent vectors, then

$$\lim_{t \rightarrow \infty} \|Am - A(t)\| = 0 \text{ and } \lim_{t \rightarrow \infty} \|Bm - B(t)\| = 0 \quad (26)$$

Morover, if Kc and Kd are dependent on t , it suffices to replace (23) by

$$\begin{aligned} C(t+1) &= \sum_{K=0}^t (I - \Gamma(k))^{-1} (Kc(k+1) \otimes \bar{\varepsilon}(k+1)H^T(K)) \\ D(t+1) &= \sum_{K=0}^t (I + \Gamma(k))^{-1} (Kd(k+1) \otimes \bar{\varepsilon}(k+1)H^T(k)). \end{aligned} \quad (27)$$

4. Model Reference Adaptive Ecological Model

The Model Reference Adaptive System with the discrete polynomial non-linear system (Yamamura(1986)) is conceived to be a useful method in specifying the balance of inter-field of the ecological model.

Then, we shall consider the following ecological growth model with discrete polynomial non-linear system. The economic activities on land depend on the ecological activities in marine and each model has its target path.

The ecological model :

$$Y_M(t+1) = (1 + \varepsilon_M - \lambda_M Y_S(t)) Y_M(t) + u_M(t-1) \quad (28)$$

Y_M : the output of ecological activities in marine.

ε_M : the potential ecological growth rate.

λ_M : the rate of effect to the economic activities on land.

The economic model :

$$Y_S(t+1) = (1 + \varepsilon_S + \lambda_S Y_M(t)) Y_S(t) + u_S(t) \quad (29)$$

Y_S : the output of economic activities on land.

ε_S : the potential economic growth rate.

λ_S : the rate of effect to the ecological activities in marine.

the input $u_M(t)$, $u_S(t)$ is represented as follows.

$$u_M(t) = (M_M(t+2) - M_M(t+1) - \tilde{d}_M(t)) - (\varepsilon_M - \tilde{\lambda}_M(t) M_S(t+1)) M_M(t+1) \quad (30)$$

$$u_S(t) = (M_S(t+1) - M_S(t) - \tilde{d}_S(t-1)) - (\varepsilon_S + \tilde{\lambda}_S(t-1) M_M(t)) M_S(t) \quad (31)$$

where, the target paths of ecological and economic model are

$$M_M(t+1) = (1 + \varepsilon_M - \tilde{\lambda}_M(t-1) M_S(t)) M_M(t) + u_M(t-1) + \tilde{d}_M(t-1) \quad (32)$$

$$M_S(t+1) = (1 + \varepsilon_S + \tilde{\lambda}_S(t-1) M_M(t)) M_S(t) + u_S(t) + \tilde{d}_S(t-1) \quad (33)$$

The state difference is represented as follows :

$$E_i^{(1)}(t) = M_i(t) - y_i(t) \quad (34)$$

The parameter difference is represented as follows :

$$\phi_i(t) = \tilde{\lambda}_i(t) - \lambda_i \quad (i = M, S) \quad (35)$$

The following equations $E_M^{(1)}(t-1)$, $E_S^{(1)}(t-1)$ are obtained through the iterative substitution of the relevant equations.

$$E_M^1(t-1) = -\phi_M(t) y_S(t-2) y_M(t-2) + \phi_M(t) + \xi_M(t-3) \quad (36)$$

$$E_S^1(t-1) = \phi_S(t) y_M(t-2) y_S(t-2) + \phi_S(t) + \xi_S(t-3) \quad (37)$$

where

$$\xi_i(t) = \tilde{d}_i(t) - d_i(t) \quad (i = M, S) \quad (38)$$

$$d_M(t-3)(E^{(1)}(t-2), E^{(1)}(t-2)) = -(1 + \varepsilon_M) E_M^{(1)}(t-2) + \tilde{\lambda}_M(t-3) E_S^{(2)}(t-2) \quad (39)$$

$$d_S(t-3)(E^{(1)}(t-2), E^{(2)}(t-2)) = -(1 + \varepsilon_S) E_S^{(1)}(t-2) - \tilde{\lambda}_S(t-3) E_S^{(2)}(t-2) \quad (40)$$

$$E_S^2(t-2) = \{G_{[2,1]}(M(t-2), M(t-2) - E(t-2)) E^{(1)}(t-2)\}^2 \quad (41)$$

$$\phi_M(t) = -(\hat{\lambda}_M(t-3) - \hat{\lambda}_M(t))y_s(t-2)y_M(t-2) \quad (42)$$

$$\phi_s(t) = (\hat{\lambda}_s(t-3) - \hat{\lambda}_s(t))y_M(t-2)y_s(t-2) \quad (43)$$

The adaptive current controller is represented as follows :

$$\begin{aligned} \hat{E}^{(1)}(t+1) &= \hat{d}(t-1) - d(t-1)(\hat{E}^{(1)}(t), \hat{E}^{(2)}(t)) \\ \hat{E}^{(2)}(2t+1) &= \{G_{[2,1]}(M(t+1), M(t+1) - \hat{E}(t+1))\hat{E}^{(1)}(t+1)\}^2 \end{aligned} \quad (45)$$

where $G_{[2,1]}$ is the transfer matrix from $E^1(t-1)$ to $E^2(t-1)$. And we can get $\hat{E}^1(t+1)$, $\hat{E}^2(t+1)$ by using adaptive current controller repeated three times from the initial values $\hat{E}^{(1)}(t-2) = E^{(1)}(t-2)$, $\hat{E}^{(2)}(t-2) = E^{(2)}(t-2)$.

$$\hat{d}(t) = d(t)(\hat{E}^{(1)}(t+1), \hat{E}^{(2)}(t+1)) \quad (46)$$

The parameter estimation equations are represented as follows :

$$\hat{\lambda}_M(t+1) = \hat{\lambda}_M(t) + a_t y_s(t-2)y_M(t-2)\varepsilon_M(t+1) \quad (47)$$

$$\hat{\lambda}_s(t+1) = \hat{\lambda}_s(t) - a_t y_M(t-2)y_s(t-2)\varepsilon_s(t+1) \quad (48)$$

$$\text{where} \quad \varepsilon(t+1) = E^1(t-1) - \phi(t) - \xi(t-3) \quad (49)$$

This mode is possible to clarify how the economic and ecological actual worlds would converge to the sustainable world when the reference world with the reference economic and ecological worlds are established.

5. Conclusion

We have investigated the Hermite Inverse Matrix Model, Model Reference Adaptive Pollution Control Model and Model Reference Adaptive Ecological Model.

The main results are as follows :

- (1) The Hermite Inverse Matrix Model is conceived to be a useful tool in elucidating the total effects of inter-field propagation.
- (2) The Model Reference Adaptive Pollution Control Model is thought to be a useful tool in specifying the adaptive processes when the reference world is established.
- (3) The Model Reference Adaptive Ecological Model is conceived to be useful for clarifying the adaptive processes when the reference economic and ecological worlds are established.

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