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Studies on The Identification Problem of The Simultaneous Economic Models From The Viewpoint of Unique Determination of Parameters (II)

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Abstract

This paper is a continuation of [14]. Using our viewpoint and methods, we study the identification of the dynamic models and obtain a number of results. We remove the usual assumption that the roots of the polynomial equation $|B_0+B_1L+\cdots+B_PL^P|=0$ lie outside the unit circle, so that we can study the identification of the unstable dynamic models. We also remove the general assumption that the exogenous variables are not connected by any linear identities. In the following paper, we shall discuss the identification problem of the nonlinear models, the error-shock models (including the unstable ones) by using the same viewpoint and methods.

§1. Introduction

In [14], proceeding from the viewpoint that the parameters to be estimated should be uniquely determined, we defined the concepts of the distinction and identification of vectors, and discussed the identification of the very general contemponaneous simulteneous models by the one-step identification method and two-step identification method. We also gave the concepts of almost identification and completely under identification. By using our viewpoint and methods, the statement of many of the principal results in identification theory was concised. In this paper we discuss the identification of the dynamic models. The concepts, terminologies, symbols relative to the identification can be seen in[14].

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§ 2. Dynamic Models

A lot of work on identification for dynamic models has been done[2][7][8]. But most study was made on how to restrict the admissible matrix $F(L)$ of polynormials in the lag operator L to an identity matrix. Thus there are more difficulties for identifying the models, and identification is confined to a part of the models.

In this section, we remove the general assumptions that the roots of $|B_0+B_1L+\cdots+B_pL^p|=0$ lie outside the unit circle[8] and that X_t are not connected by any linear identity as well as the conditions which are difficult to verify and satisfy[8]. We discuss the identification of more general dynamic models with the points and methods in the present paper and obtain the theorems for identification which are similar to contemporaneous models.

The assumption that the roots of $|B_0+B_1L+\cdots+B_pL^p|=0$ lie outside the unit circle serves to ensure that $\{y_t\}$ is weakly stationary and the variance sequence $\{\mathrm{var}(y_t)\}$ is not divergent [13]. The autoregressive process $\sum_{j=0}^{p}B_jY_{t-j}+\sum_{j=0}^{q}r_jX_{t-j}=U_t$ can then be expressed as the infinite moving average process $Y_t=\sum_{j=0}^{\infty}\pi_jx_{t-j}+\sum_{j=0}^{\infty}D_jU_{t-j}$ [1] However consistent estimators of parameters may exist without the assumption as long as the parameters of the model are uniquely determined*, and from the view-point of economic theory, some people do consider that economic systems are almost unstable, and disturbance at every initial point will keep on dispersing with the shift of time, one relies on artificial restrictions to hold back such dispersion [11]. Thus,

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*To show this, we consider the simple model

$$y_t=\beta y_{t-1}+\varepsilon_t'$$

where $\beta>1$, $E\,\varepsilon_t=0$, and ε_t is weakly stationary. We have

$$\hat{\beta}=\frac{\sum_{t=1}^{T}y_ty_{t-1}}{\sum_{t=1}^{T}y_{t-1}^2}=\beta+\frac{\sum_{t=1}^{T}\varepsilon_ty_{t-1}}{\sum_{t=1}^{T}y_{t-1}^2}.$$

We only need to prove

$$\frac{\sum_{t=1}^{T}\varepsilon_ty_{t-1}}{\sum_{t=1}^{T}y_{t-1}^2}\xrightarrow{a.e}0\quad(T\to+\infty).$$

since $$\left|\frac{\sum_{t=1}^{T}\varepsilon_ty_{t-1}}{\sum_{t=1}^{T}y_{t-1}^2}\right|\leqslant\frac{\sum_{t=1}^{T}|\varepsilon_t|\,|y_{t-1}|}{\sum_{t=1}^{T}y_{t-1}^2}\overset{a.e}{\leqslant}M\frac{\sum_{t=1}^{T}|y_{t-1}|}{\sum_{t=1}^{T}y_{t-1}^2},$$

where M is a positive integer, we only need to prove it seems necessary to study the identifiability of unstable dynamic models.

Consider the following model

$$\sum_{j=0}^{p} B_j y_{t-j} + \sum_{j=0}^{q} \Gamma_j X_{t-j} = U_t' \qquad (2.1)$$

where Y_t, X_t and U_t are respectively $G\times 1$, $K\times 1$ and $G\times 1$ vectors of observed endogenous variables, exogenous variables and unobserved disturbance terms at time t; B_j and Γ_j are respectively $G\times G$ and $G\times K$ parameter matrices. Rewriting (2.1) in terms of the lag operator L, $LY_t = Y_{t-1}$, we have

$$B(L)Y_t + \Gamma(L)X_t = U_t, \qquad (2.2)$$

where

$$B(L) = B_0 + B_1 L + \cdots + B_p L^p, \qquad (2.3)$$

$$\Gamma(L) = \Gamma_0 + \Gamma_1 L + \cdots + \Gamma_q L^q. \qquad (2.4)$$

Assumption 2.1 B_0 is nonsingular.

Assumption 2.2 X_t is stationary in a wide sense, ergodic and has finite second moments, and is independent of the U_t sequences**.

Assumption 2.3 $EU_t = 0$, and $\{U_t\}$ is weakly stationary.

We denote the sequence of the second order moments by

$$C_U(\tau) = EU_t U'_{t-\tau} \quad (\tau = 0,\ 1\cdots,\ +\infty). \qquad (2.5)$$

$$\frac{\sum_{t=1}^{T} |y_{t-1}|}{\sum_{t=1}^{T} y^2_{t-1}} \xrightarrow{a.e} 0 \ (T\to+\infty).$$

As $\beta>1$, we know $|y_{t-1}| \xrightarrow{a;e} +\infty \ (t\to+\infty)$.

Let $V_T = \sum_{t=1}^{T} |y_{t-1}|$, $Z_T = \sum_{t=1}^{T} y^2_{t-1}$,

then $V_T \xrightarrow{a;e} +\infty$, $Z_T \xrightarrow{a,e} +\infty$ $(T\to+\infty)$, and there exists a positive integer N,

$$Z_T - Z_{T-1} = y^2_{T-1} > 0 \ (a,\ e).$$

Thus, by the O.stolz theorem in mathematical analysis, we have

$$\frac{\sum_{t=1}^{T} |y_{t-1}|}{\sum_{t=1}^{T} y^2_{t-1}} = \frac{V_T}{Z_T} \overset{a,e}{=} \frac{V_T - V_{T-1}}{Z_T - Z_{T-1}} = \frac{|y_{t-1}|}{y^2_{t-1}} \overset{a,e}{=} \frac{1}{|y_{t-1}|} \overset{a,e}{=} 0 (T\to+\infty),$$

Which proves $\dfrac{\sum_{t=1}^{T} \varepsilon_t y_{t-1}}{\sum_{0=1}^{T} y^2_{t-1}} \xrightarrow{a.e} 0$ $(T\to+\infty)$. Hence $\hat{B}$ is the consistent estimator of B.

In fact when U_t is serially uncorrelated, we do approach the identifiability of the dynamic models as if they are contemporaneous. For the lagged endogenous variables in this case can be regarded as predetermined.

** The assumption that X_t is weakly stationary can be removed.

Denote

$$B=(B_0,\ B_1,\ \cdots,\ B_p); \tag{2.6}$$

$$\Gamma=(\Gamma_0,\ \Gamma_1,\ \cdots,\ \Gamma_q); \tag{2.7}$$

$$\bar{Y}_t=\begin{pmatrix} Y_t \\ Y_{t-1} \\ \vdots \\ Y_{t-p} \end{pmatrix}; \qquad \bar{X}_t=\begin{pmatrix} X_t \\ X_{t-1} \\ \vdots \\ X_{t-q} \end{pmatrix}. \tag{2.8}$$

Then (2.1) can be rewritten as

$$B\bar{Y}_t+\Gamma\bar{X}_t=U_t. \tag{2.9}$$

By Assumption 2.2, we have

$$BC_{\bar{Y}\bar{X}}(\tau,\ t-\tau)+\Gamma C_{\bar{X}}(\tau)=0 \qquad (\tau=0,\ 1,\ \cdots,\ +\infty), \tag{2.10}$$

where

$$C_{\bar{X}}=E\bar{X}_t\bar{X}_{t-\tau}$$

$$=\begin{pmatrix} C_X(\tau) & C_X(\tau+1) & \cdots & C_X(\tau+q) \\ C_X(\tau+1) & C_X(\tau) & \cdots & C_X(\tau+q-1) \\ \cdots & \cdots & \cdots & \cdots \\ C_X(\tau+q) & C_X(\tau+q-1) & \cdots & C_X(\tau) \end{pmatrix} \quad (\tau=0,\ \cdots,\ +\infty) \tag{2.11}$$

is a $k(q+1)\times k(q+1)$ symmetric matrix, in which $C_X(j)=EX_{t-k}X'_{t-i}(j=i-k)$ is a $k\times k$ symmetric matrix;

$$C_{\bar{Y}\bar{X}}(t,\ t-\tau)=E\bar{Y}_t\bar{X}'_{t-\tau}$$

$$=\begin{pmatrix} C_{YX}(t,\ t-\tau) & C_{YX}(t,\ t-\tau-1) & \cdots & C_{YX}(t,\ t-\tau-q) \\ C_{YX}(t-1,\ t-\tau) & C_{YX}(t-1,\ t-\tau-1) & \cdots & C_{YX}(t-1,\ t-\tau-q) \\ \cdots & \cdots & \cdots & \cdots \\ C_{YX}(t-p,\ t-\tau) & C_{YX}(t-p,\ t-\tau-1) & \cdots & C_{YX}(t-p,\ t-\tau-q) \end{pmatrix}$$

$$(t=0,\ \cdots,\ +\infty) \tag{2.12}$$

is a $G(p+1)\times k(q+1)$ matrix, in which $C_{YX}(t-i,\ t-\tau-j)$

$$=EY_{t-i}X'_{t-\tau-j}\begin{pmatrix} i=0,\ \cdots,\ p \\ j=0,\ \cdots,\ q \end{pmatrix} \text{is a}$$

$(p+1)\times(q+1)$ matrix

$$C_u(\tau)=EU_tU'_{t-\tau}=E(B\bar{Y}_t+\Gamma\bar{X}_t)(B\bar{Y}_t+\Gamma\bar{X}_t)',$$

$$=BC_{\bar{y}}(t,\ t-\tau)B'+\Gamma C_{\bar{X}\bar{Y}}(t,\ t-\tau)B'+BC_{\bar{Y}\bar{X}}(t,\ t-\tau)\Gamma'+\Gamma C_{\bar{X}}(\tau)\Gamma'$$

$$(\tau=0,\ 1,\ \cdots,\ +\infty), \tag{2.13}$$

where

$$C_{\bar{Y}}(\tau)=E\bar{Y}_t\bar{Y}'_{t-\tau}$$

$$=\begin{pmatrix} C_Y(t,\ t-\tau) & C_Y(t,\ t-\tau-1) & \cdots & C_Y(t,\ t-\tau-p) \\ C_Y(t-1,\ t-\tau) & C_Y(t-1,\ t-\tau-1) & \cdots & C_Y(t-1,\ t-\tau-p) \\ \cdots & \cdots & \cdots & \cdots \\ C_Y(t-p,\ t-\tau) & C_Y(t-p,\ t-\tau-1) & \cdots & C_Y(t-p,\ t-\tau-p) \end{pmatrix}$$

$$(\tau=0,\ 1,\ \cdots,\ +\infty) \tag{2.14}$$

is a $G(p+1)\times G(p+1)$ matrix, in which $C_Y(t-i,\ t-j-\tau)=EY_{t-j}Y'_{t-\tau-j}(i,\ j=0,\ \cdots,\ p)$ is a $(p+1)\times(p+1)$ matrix

When $\tau=0$, by (2.10), (2.13) becomes

$$C_u(0)+\Gamma C_{\bar{X}}(0)\Gamma'=BC_{\bar{Y}}(t,\ t)B'. \tag{2.15}$$

If B and Γ are identified, from(2.13), $C_u(\tau)$ can also be uniquely betermined ($\tau=0,\ 1,\ \cdots,\ +\infty$). Rewrite (2.10) as

$$(B,\ \Gamma)\begin{pmatrix} C_{\overline{YX}}(t,\ t) & C_{\overline{YX}}(t,\ t-1)\cdots \\ C_{\bar{X}}(0) & C_{\bar{X}}(1)\cdots \end{pmatrix}=0. \tag{2.16}$$

Denote by W the matrix obtained by detecting the identical columns of the observed matrix in (2.16) and write

$$A=(B,\ \Gamma), \tag{2.17}$$

(2.16) can be rewritten as

$$AW=0. \tag{2.18}$$

Clearly, for the g-th row A_g of A, we have

$$AW_g=0, \tag{2.19}$$

where

$$W=\begin{pmatrix} C_{YX}(t,\ t)\ C_{YX}(t,\ t-1)\ C_{YX}(t,\ t-2)\cdots \\ C_{YX}(t-1,\ t)\ C_{YX}(t-1,\ t-1)C_{YX}(t-1,\ t-2)\cdots \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ C_{YX}(t-p,\ t)\ C_{YX}(t-p,\ t-1)\ C_{YX}(t-p,\ t-2)\cdots \\ C_X(0)\ C_X(1)\ C_X(2)\cdots \\ C_X(1)\ C_X(0)\ C_X(1)\cdots \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ C_X(q)\ C_X(q-1)\ C_X(q-2)\cdots \end{pmatrix}. \tag{2.20}$$

Denote rank $(W)=k^\circ$. Since rank $(A)=\text{rank}(B_0)=G$, $\text{rank}(W)=k^\circ\leqslant Gp+k(q+1)$ from Lemma 2.1 in Reference[14]. When $k^\circ<Gp+k(q+1)$, A is not a basis for the row kernel of W. Then from Lemma 2.2 in Reference[14]. there exist $Gp+k(q+1)-k^\circ$ solution vectors $C_1,\ C_2,\cdots,C_{Gp+k(q+1)-k^\circ}$ linearly independent of the rows of A such that

$$\bar{A}=\begin{pmatrix} A \\ C_1 \\ C_2 \\ \vdots \\ C_{Gp+k(q+1)-k^\circ} \end{pmatrix} \tag{2.21}$$

is a basis for the row kernel of W, then we have

$$\bar{A}W=0. \tag{2.22}$$

By Theorem 2.1 in [14], A_g is completely underidentifiable if observational information alone is available. However, if we also know the restrictions on A_g

$$A_g\phi_g=d_g. \tag{2.23}$$

such that where ϕ_g is a $[G(p+1)+k(q+1)]\times R_g$ matrix with known elements; d_g is a $1\times R_g$ vector with known elements, then by Theorem 2.4 in [14] and corollary 2.1, in [14] we have

Theorem 2.1 Under Assumptions 2.1—2.3 and the restrictions (2.19) and (2.23), A_g is identified if and only if

$$\text{rank}(\bar{A}\phi_g)=\begin{cases}G(p+1)+k(q+1)-k^\circ, & d_g\neq 0;\\ G(p+1)+k(q+1)-k^\circ-1, & d_g=0.\end{cases}$$

Corollary 2.1 Under Assumptions 2.1—2.3, and the restrictions (2.19) and (2.23), a necessary condition for the identifiability of A_g is

$$R_g\geqslant\begin{cases}G(p+1)+k(q+1)-k^\circ, & d_g\neq 0;\\ G(p+1)+k(q+1)-k^\circ-1, & d_g=0.\end{cases}$$

Corollary 2.2 Under Assumptions 2.1—2.3 and the restrictions (2.19) and (2.23), when $k^\circ=Gp+k(q+1)$, A_g is identified if and only if

$$\text{rank}(A\phi_g)=\begin{cases}G, & d_g\neq 0;\\ G-1, & d_g=0.\end{cases}$$

Next, we discuss the identifiability of A_g or A by applying the one-step identification method.

(2.19) and (2.23) can be rewritten as

$$A_g(\phi_g\ \vdots\ W)=(d_g\ \vdots\ 0). \tag{2.24}$$

Theorem 2.2 Under Assumptions 2.1—2.3 and the restriction (2.24), A_g is identified if and only if

$$\text{rank}(\phi_g\ \vdots\ W)=\begin{cases}G(p+1)+k(q+1), & d_g\neq 0;\\ G(p+1)+k(q+1)-1, & d_g=0.\end{cases}$$

Stacking A in one row, i.e. $\vec{A}=(A_1, A_2, \cdots, A_G)'$, then (2.18) can be rewritten as

$$(I_G\otimes W')\vec{A}=0. \tag{2.25}$$

$\vec{A}$ has the restriction

$$\phi\vec{A}=d, \tag{2.26}$$

where ϕ is an $R\times[G(p+1)+k(q+1)]G$ matrix with known elements; d_g is an $R\times 1$ column vector with known elements and $d\neq 0$. Denote

$$Q=\begin{bmatrix}\phi\\ I_G\otimes W'\end{bmatrix},\qquad \bar{d}=\begin{bmatrix}d\\ 0\end{bmatrix}. \tag{2.27}$$

Then we have

$$Q\vec{A}=\bar{d}. \tag{2.28}$$

Theorem 2.3 Under Assumptions 2.1—2.3 and the restriction (2.28), $\vec{A}$ is identified if and only if rank (Q) is equal to $[G(p+1)+k(q+1)]G$.

Corollary 2.3 Under Assumptions 2.1—2.3 and the restriction(2.28), a necessary condition for the identifiability of $\vec{A}$ is

$$R > G[G(p+1)+k(q+1)-k^{\circ}]$$

Example: To illustrate the application of the conditions for identifiability by our identification method, we consider a two-equation simple dynamic system

$$B_0 Y_t + B_1 Y_{t-1} + TX_t = U_t, \tag{2.29}$$

i.e.,

$$\begin{bmatrix} B_{11,0} & B_{12,0} \\ B_{21,0} & B_{22,0} \end{bmatrix}\begin{bmatrix} Y_{1t} \\ Y_{2t} \end{bmatrix}+\begin{bmatrix} B_{11,1} & B_{12,1} \\ B_{21,1} & B_{22,1} \end{bmatrix}\begin{bmatrix} Y_{1t-1} \\ Y_{2t-1} \end{bmatrix}+\begin{bmatrix} r_{11} & r_{12} \\ r_{21} & r_{22} \end{bmatrix}\begin{bmatrix} x_{1t} \\ x_{2t} \end{bmatrix}=\begin{bmatrix} U_{1t} \\ U_{2t} \end{bmatrix}. \tag{2.29'}$$

In this case,

$$A=\begin{bmatrix} B_{11,0} & B_{12,0} & B_{11,1} & B_{12,1} & r_{11} & r_{12} \\ B_{21,0} & B_{22,0} & B_{21.} & B_{22,1} & r_{21} & r_{22} \end{bmatrix}, \tag{2.30}$$

$$W=\begin{pmatrix} C_{YX}(t,t) & C_{YX}(t,t-1)\cdots\cdots \\ C_{YX}(t-1,t) & C_{YX}(t-1,t-1)\cdots\cdots \\ C_X(0) & C_X(1)\cdots\cdots \end{pmatrix}$$

$$=\begin{pmatrix} C_{Y_1X_1}(t,t) & C_{Y_1X_2}(t,t) & C_{Y_1X_1}(t,t-1) & C_{Y_1X_2}(t,t-1)\cdots \\ C_{Y_2X_1}(t,t) & C_{Y_2X_2}(t,t) & C_{Y_2X_1}(t,t-1) & C_{Y_2X_2}(t,t-1)\cdots \\ C_{Y_1X_1}(t-1,t) & C_{Y_1X_2}(t-1,t) & C_{Y_1X_1}(t-1,t-1) & C_{Y_1X_2}(t-1,t-1)\cdots \\ C_{Y_2X_1}(t-1,t) & C_{Y_2X_2}(t-1,t) & C_{Y_2X_1}(t-1,t-1) & C_{Y_2X_2}(t-1,t-1)\cdots \\ C_{X_1X_1}(0) & C_{X_1X_2}(0) & C_{X_1X_1}(1) & C_{X_1X_2}(1)\cdots \\ C_{X_1X_2}(0) & C_{X_2X_2}(0) & C_{X_1X_2}(1) & C_{X_2X_2}(1)\cdots \end{pmatrix} \tag{2.31}$$

We normalize the equations by letting $B_{11,0}=1=B_{22,0}$. Suppose the constraint for parameters of the first equation is

$$r_{11}=0,$$

and the constraints for parameters of the second equation are

$$B_{22,1}=0 \qquad r_{21}+r_{22}=1.$$

Then

$$\phi_1'=\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}, \qquad d_1=(1\ \ 0); \tag{2.32}$$

$$\phi_2'=\begin{pmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 \end{pmatrix}, \qquad d_2=(1,0,1). \tag{2.33}$$

1° When rank$(W)=4$, then $k^\circ=k$. Thus

$$\text{rank}(A\phi_1)=\text{rank}\begin{bmatrix}1 & 0\\ B_{21,0} & r_{21}\end{bmatrix}=2,$$

$$\text{rank}(A\phi_2)=\text{rank}\begin{bmatrix}B_{12,0} & B_{12,1} & r_{12}\\ 1 & 0 & 1\end{bmatrix}=2.$$

By Theorem 2.1, they are both identified.

2° rank$(W)=k^\circ=3$.

Since A is not a basis for the row kernel of W, there exists a solution vector $a=(a_1,a_2,\cdots,a_6)$ of Eq. $xW=0$ such that

$$\bar{A}=\begin{pmatrix}B_{11,0} & B_{12,0} & B_{11,1} & B_{12,1} & r_{11} & r_{12}\\ B_{21,0} & B_{22,0} & B_{21,1} & B_{22,1} & r_{21} & r_{22}\\ a_1 & a_2 & a_3 & a_4 & a_5 & a_6\end{pmatrix}$$

constitutes a basis for the now kernel of W. we thus have

$$\text{rank}(\bar{A}\phi_1)=\text{rank}\begin{pmatrix}1 & 0\\ B_{21,0} & r_{21}\\ a_1 & a_5\end{pmatrix}=2<G(p+1)+k(q+1)-k^\circ=3,$$

$$\text{rank}(\bar{A}\phi_2)=\text{rank}\begin{pmatrix}B_{12,0} & B_{12,1} & r_{12}\\ 1 & 0 & 1\\ a_2 & a_4 & a_5+a_6\end{pmatrix}$$

$$=\text{rank}\begin{pmatrix}B_{12,0} & B_{12,1} & r_{12}-B_{12,0}\\ 1 & 0 & 0\\ a_2 & a_4 & a_5+a_6-a_2\end{pmatrix}$$

By Theorem 2.1,the first equation is completely underidentifiable.when $B_{21,1}(a_5+a_6-a_2)\neq a_4(r_{12}-B_{12,0})$, the second equation is still identified by Theorem 2.1. Since the Lebesgue measure of the point set on which rank$(\bar{A}\phi_2)\neq 3$ is equal to zero, the second equation is almost identifiable.

3° rank$(W)=k^\circ=2$.

Since $R_1=2<G(p+1)+k(q+1)-k^\circ=4$,

$R_2=3<4$,

hence the two equations are both completely underidentifiable.

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从参数唯一确定的观点论联立经济模型的识别问题(Ⅱ)

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提 要

本文继续利用文献〔14〕的观点和方法研究了动态模型的识别问题并且得到了若干有意义的结果。文中移去了“要求矩阵多项式方程$|B_0+B_1L+\cdots+B_pL^p|=0$的根全部位于单位圆外”的假定，这样使得我们能够讨论非稳定的动态模型。文中还去掉“外生变量不由任何线性恒等式连接”的通常假定。由于这两个假定的去掉，使得我们利用一步识别法和二步识别法大大地扩大充讨论的范围。随同另文，我们将利用同样的观点和方法来探讨非线性模型、误差冲击模型(包括非稳定的动态误差模型)，也将得到类似的结果。