Adv Syst Sci Appl 2017; **17**(2); 14-28
Published online http://ijassa.ipu.ru/ojs/ijassa/article/view/12

Economic Security under Disturbances of Foreign Capital

Kurt Schimmel[1)], Sifeng Liu[2,3)], Jeananne Nicholls[1)], Nicholas A. Nechval[4)],
Jeffrey Yi-Lin Forrest[1)]

[1)] *School of Business, Slippery Rock University, Slippery Rock, PA16057, U.S.A.*

E-mail: Kurt.schimmel@sru.edu; Jeananne.nicholls@sru.edu; Jeffrey.forrest@sru.edu

[2)] *Institute for Grey System Studies, Nanjing University of Aeronautics and Astronautics, Nanjing 211106, PR China*

[3)] *Centre for Computational Intelligence, De Montfort University, Leicester LE1 9BH, UK;*

E-mail: sfliu@nuaa.edu.cn

[4)] *Department of Mathematics, Baltic International Academy, Lomonosov Street 4, Riga LV-1019, Latvia*

E-mail: nechval@junik.lv

Abstract: Considering spillover effects of foreign capital, this paper establishes a method for the receiving economy to constantly monitor and forecast the movement of foreign capital within itself so that methods of regulation could be established to guarantee the health and stable development (or the security) of the domestic economy. Methods of control theory are employed to model the movement of foreign capital, to estimate the initial state of foreign capital's movement. On the method established and the systemic yoyo model, this paper introduces ways to prevent foreign capital from adversely impacting the receiving economy for establishing theoretical guidance for insuring the healthy development of the economy. This paper provides several practically useful strategies that could counter disturbances caused by foreign capital within the receiving economy and protect the economic security of the system in order to avoid the disastrous aftermath of the currency war that occurs along with large scale withdraw of foreign capital that was initially invested within the system in friendly terms.

Keywords: movement of money, economic stability, method of control, estimation, systemic yoyo model, strategies of regulation

1. INTRODUCTION

Sequel to [7], this paper establishes a theoretical model on how to monitor the movement of foreign capital within a nation's economy in order to keep the economic security of the economy intact. In particular, this paper is organized as follows: Section 2 establishes a theoretical model for monitoring the dynamics of foreign capital within a nation's economy. Section 3 studies how to estimate the state of motion of foreign capital within the domestic economy. Section 4 fills the need of estimating the initial state of foreign capital's movement. Section 5 explores some potential measures useful for countering the fluctuations of foreign capital within a national economy. Section 6 concludes the presentation of this work.

2. A MODEL FOR MONITORING DYNAMIC FOREIGN CAPITAL WITHIN AN ECONOMIC SYSTEM

The receiving economic system foreign investment is really a double-edged sword. It can not only provide sufficient capital, advanced technological equipment, and excellent management experience for the development of the economic system, but also seriously constrain the development of domestic enterprises, weaken the innovation capacity of the economic system, and create serious security risks for the economic system [7]. Hence, practically speaking, there is an urgent need to appropriately formulate and implement strategic measures regarding foreign investments in order to accelerate the economic development by sufficiently taking advantage of foreign capital while lowering the security risk that accompanies the influx of foreign capital to a certain level or within the controllable range of the economic system. This section attempts to provide theoretically sound suggestions regarding the design of foreign capital policies and strategies for the receiving economic system by modeling the scale, regions, and areas of foreign investment, and by constructing a control-theory model for foreign investment.

Generally speaking, the investment within an economic system by foreign capital may be maintained at a certain stable speed without being affected by regional economic development cycles, financial shocks, and major changes in the environment of the economic system. For example, since 1992, China has been continuously attracting a large scale of foreign investment [1]. And only in some very particular situations, such as major financial shocks, drastic changes in the political environment of the economic system, etc., the invested foreign capital would show speculative, withdrawal and other behaviors.

From what has been discussed in [7], it follows that foreign capital affects the economic security of the receiving economic system in three different ways: One is the magnitude of the invested foreign capital, two is the geographic distribution of the foreign investments, and three the difference between the actual distribution of invested foreign capital and the need distribution for foreign capital investment of the economic system.

In terms of the magnitude of invested foreign capital, a rising magnitude increases the holding of foreign currencies of the economic system while it also increases the internal base money supply. That might affect adversely the effectiveness of the adopted monetary policies of the economic system. Additionally, the rising amount of foreign investment also increases the uncertainty of how the economic system would be influenced by the external world. Because of its drive for profit, foreign capital might leave the economic system in large scales within a short period of time when the economic system experiences shocks from the external environment. That exit could cause disastrous consequences for the healthy development of the economic system, and such effects had been sufficiently manifested in the Southeast Asian financial crises of the 1990s.

In terms of the geographic distribution of foreign investments, when the imbalance in the geographic distribution of foreign investment goes up, the internal development imbalance within the economic system will expand, which might cause chaos in the regional development of the economic system so that the orderly domestic allocation of resources will be disrupted, such wasteful phenomena of resources as duplicated constructions, production overcapacity, etc., will likely to appear. In terms of the difference between the actual distribution of invested foreign capital and the need distribution for foreign capital investment of the economic system, it creates an imbalanced local distribution of regional industries within the economic system. That causes the internal industrial structure of the economic system to lose its balance so that when affected by external uncertainties, the development of the economic system will be badly hindered by production imbalances and insufficient productions of some industries. For example, in some of the emerging economies foreign investment is relatively concentrated in a few industries. When such an economic system is affected by financial shocks, a quick withdraw of foreign capital generally leaves behind damaging effects for the development and stability of the economic system [3].

Therefore, in the following, we use $r(k)$ to stand for the magnitude of foreign investment at time t_k within the economic system, $\alpha(k)$ – the geographic distribution of foreign investment at time t_k, and $\beta(k)$ for the difference between the actual industrial distribution of foreign investment and the actual distribution of areas that need foreign investment at time t_k. Here, we utilize the difference $\beta(k)$ to measure the effect of foreign capital on the economic security of the economic system at time t_k . Next, let us establish a control and monitor equation of these three variables in order to materialize the estimation and regulation of the state of foreign capital at any chosen time moment.

Additionally, in order to produce meaningful anticipation on the state of investment of foreign capital, let us use $\dot{r}(k)$, $\dot{\alpha}(k)$, and $\dot{\beta}(k)$ to respectively denote the rate of change of the investment magnitude $r(k)$ of foreign capital, the rate of change of the geographic distribution of foreign investment $\alpha(k)$, and the rate of change in the difference $\beta(k)$ between the actual industrial distribution of foreign investment and the actual distribution of areas that need foreign investment at time t_k.

If we let $x(k)$ be the state vector of foreign capital within the economic system, where

$$x(k)=\begin{bmatrix} x_1(k)\\ x_2(k)\\ x_3(k)\\ x_4(k)\\ x_5(k)\\ x_6(k) \end{bmatrix}=\begin{bmatrix} r(k)\\ \dot{r}(k)\\ \alpha(k)\\ \dot{\alpha}(k)\\ \beta(k)\\ \dot{\beta}(k) \end{bmatrix}=\begin{bmatrix} \text{magnitude of investmnent at } t_k\\ \text{rate of change in investment at } t_k\\ \text{geographic distribution of investment at } t_k\\ \text{rate of change in geo} - \text{distribution at } t_k\\ \text{difference between investment and need at } t_k\\ \text{rate of change in investment/need difference at } t_k \end{bmatrix}$$

then we can use the following state equation to describe the movement of foreign capital within the economic system:

$$x(k)=\Phi x(k-1) \tag{2.1}$$

where Φ is a matrix defined below with T representing the time interval between consecutive observations,

$$\Phi=\begin{bmatrix} 1 & T & & & & \\ 0 & 1 & & & & \\ & & 1 & T & & \\ & & 0 & 1 & & \\ & & & & 1 & T\\ & & & & 0 & 1 \end{bmatrix}.$$

However, due to the existence of various disturbances and errors in real life, the movement, when seen as a system, of foreign capital within the economy is constantly affected somehow. For example, no matter how we establish the dynamic equation, it will not be an accurate expression of the realistic system; because of the interferences of the environment that is external to the economic system, exchange rate, politics, etc., the state of foreign capital movement is affected by countless many random factors. Let us aggregate all these various known and unknown factors into one concept: process (or dynamic) noise. In order to more realistically reflect the true dynamics of the foreign capital movement, let us add a noise term $w(k)$ that describes all kinds of interferences into the previous equation. So, the state equation in eq. (2.1) can be rewritten as follows:

$$x(k) = \Phi x(k-1) + Tw(k-1) \tag{2.2}$$

where $w(k) = [w_1(k), w_2(k), w_3(k)]^T$ is the random interference of the foreign capital movement system within the economic system with w_1, w_2, and w_3 respectively being the random accelerations in the directions of r, α, and β, and matrix T is given below where T is the time interval between two consecutive observations

$$T = \begin{bmatrix} T^2/2 & & \\ T & & \\ & T^2/2 & \\ & T & \\ & & T^2/2 \\ & & T \end{bmatrix}.$$

Of particular interest is that the interference $\{w(k)\}$ as introduced above is a stochastic sequence, which comprehensively (and approximately) reflects the interference as experienced by the foreign capital when it moves within the economic system. Although there might be a large number of factors that interfere with the movement of foreign capital within the economic system, the effect of each factor might be quite small, which is likely unclear to the regulator of the system and cannot be readily measured. Even so, the total effect of all the interfering factors on the system's dynamics can be described by using a stochastic sequence (or a stochastic process if the movement system is modeled by a continuous model).

However, it is still not enough for us to only employ eq. (2.2) to describe the movement of foreign capital within the economic system. For the general scenario, the economic system can acquire and observe some traces of the movement of the foreign capital by using various methods of statistics. However, what is acquired and observed tends to be only about some components of the state variable or the values of some linear transformations of the state variable. For example, when using econometric data to observe or measure the state of foreign capital, only the magnitude, locations of investment, and industries of investment of foreign capital can be observed and measured. However, the acceleration and other parameters of movement of foreign capital are difficult to measure directly. Let us denote the data values that are actually observed as $y(k)$, where

$$y(k) = \begin{bmatrix} y_1(k) \\ y_2(k) \\ y_3(k) \end{bmatrix} = \begin{bmatrix} r(k) \\ \alpha(k) \\ \beta(k) \end{bmatrix} = \begin{bmatrix} \text{observed magnitude of investment at } t_k \\ \text{observed geo} - \text{distribution of investment at } t_k \\ \text{observed difference of investment / need at } t_k \end{bmatrix}$$

Hence, the observation (or measurement) equation that describes the movement system of foreign capital within the economic system can be established as follows:

$$y(k) = Hx(k) \tag{2.3}$$

where

$$H = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

It can be expected that when econometric data are employed as observations of the movement of foreign capital, there is always error. Such error could originate either from the inaccuracy of the observation equation or the method used during the statistical process and the random error that exists in the available data [6]. Let us refer this sort of error as observation (or measurement) noise. To realistically reflect the relationship between the observed variables regarding the movement of foreign capital within the economic system, let us add a random variable $v(k)$ into eq. (2.3) to describe such random interference. Hence, the observation (or measurement) equation becomes:

$$y(k) = Hx(k) + v(k) \tag{2.4}$$

where $v(k)=[v_1(k), v_2(k), v_3(k)]^T$, and $v_1(k)$, $v_2(k)$, and $v_3(k)$ are respectively the observed values of r, α, and β at time moment t_k, and $\{ v(k)\}$ is a stochastic sequence.

Now, if we combine eq. (2.2), which is the state equation that describes the movement system of foreign capital within the economic system, and the observation equation (4), which describes how the movement system of foreign capital is measured, we then obtain the following state equation of the foreign capital that expresses how the capital moves within the economic system:

$$\begin{cases} x(k) = \Phi x(k-1) + Tw(k-1) \\ y(k) = Hx(k) + v(k) \end{cases} \tag{2.5}$$

Because the movement system of foreign capital within the economic system, as described by equ. (5), contains random interferences, we will refer the system described by eq. (2.5) as a stochastic control system. For each of such systems, all obtained information (data) is “polluted” by noise. In order to obtain relatively more accurate information of the state, we will have to make our best estimation of the true state of the system from the available information (that is generally a sequence of observations) with interfering noise, which might even be incomplete. Additionally, for stochastic control systems, the process of movement itself and the observation of the system’s output are all contaminated with noise [6]. So, to study the movement of the system quantitatively we must first describe the interfering noise quantitatively.

From the knowledge of stochastic processes, it follows that the distribution of the given stochastic sequence determines all the statistical characteristics of the sequence [2]. However, generally it is difficult to fully know the distributional structure of a stochastic sequence. Therefore, when solving practical problems, it will be mostly enough to simply know some of the main statistical characteristics of the given stochastic sequence. Assume that $\{v(k)\}$ is a stochastic sequence. If for any positive integer n and t, and n arbitrary time moments $k_1 < k_2 <\ldots< k_n$, $v(k_1),\ldots, v(k_n)$ and $v(k_1+t),\ldots, v(k_n+t)$ have the same joint distribution function, then the sequence $\{v(k)\}$ is known as stationary. If the mean of the stationary stochastic sequence $\{v(k)\}$ is 0, and its auto-covariance satisfies

$$R(i,j)=\sigma^2\delta_{ij}\ ,\ \delta_{ij}=\begin{cases}0, if\ i\neq j\\ 1, if\ i\neq j\end{cases} \tag{2.6}$$

then $\{v(k)\}$ is known as a white noise sequence. Here, a white noise sequence can be fathomed as a pure stochastic sequence, satisfying that the values of any two consecutive terms are independent.

If in eq. (2.5), which describes the movement of foreign capital within the economic system, we know the state equation and the statistical characteristics of the noise, then we can move ahead to estimate the state of the movement system of foreign capital. In order to establish a formula to estimate $x(k)$ in the state equation in eq. (2.5), let us impose some conditions on the noises $\{w(k)\}$ and$\{v(k)\}$. First, let us assume that the observation noise $\{v(k)\}$ and the process dynamic noise $\{w(k)\}$ are completely independent of each other; otherwise, they can no longer be known as noise. That is, we have

$$E[w_k v_j^T]=0\text{, for any } k>0, j>0. \tag{2.7}$$

Secondly, we assume that both $\{w(k)\}$ and $\{v(k)\}$ are zero mean white noise stochastic sequences. That is, these sequences satisfy the following: For $\{w(k)\}$, we have

$$E[w(k)w^T(j)]=Q(k)\delta_{kj},$$

where

$$Q(k)=\begin{bmatrix}Q_1(k) & & \\ & Q_2(k) & \\ & & Q_3(k)\end{bmatrix},\ \delta_{kj}=\begin{cases}1, k=j\\ 0, k\neq j\end{cases}$$

which is known as the covariance matrix of the process noise, and $Q_1(k)$, $Q_2(k)$, and $Q_3(k)$ are respectively the stochastic acceleration variances of the objective along the directions r, α, and β at time moment t_k, which can be selected based on how freely foreign capital can move within the economic system and how accurate the estimate of the state needs to be.

And for$\{v(k)\}$, we have

$$E[v(k)v^T(j)]=R(k)\delta_{kj},$$

where

$$R(k)=\begin{bmatrix}R_1(k) & & \\ & R_2(k) & \\ & & R_3(k)\end{bmatrix}$$

which is known as the covariance matrix of the measurement; and $R_1(k)$, $R_2(k)$, and $R_3(k)$ are respectively the observation noise variances of the objective along the directions of r, α, and β at time moment t_k. Their values are related to the accuracy of the observation statistics and the state of foreign capital. As a matter of fact, if the noises are not of zero means or if $\{w(k)\}$ and $\{v(k)\}$ are not independent stochastic sequences, etc., then necessary mathematical treatments will be needed. Of course, that will surely involve a lot of computational complexities.

Other than the afore-mentioned basic assumptions about the random inference variables, we also need to assume that the initial state x_0 is also a random vector satisfying $E[x_0]=\bar{x}_0$, $E[(x_0-\bar{x}_0)(x_0-\bar{x}_0)^T]=P_0$, and that x_0 and w_k, v_k are independent.

3. ESTIMATE THE STATE OF MOTION OF FOREIGN CAPITAL

At the initial time moment t=0, the ideal estimate of x_0 is of course $\hat{x}_0=Ex_0=\bar{x}_0$. If we assume that we have already obtained $\bar{x}_0$, and let $\hat{x}_0=\bar{x}_0$, then the covariance matrix of the estimation error of the state is $P_0=E[(x_0-\bar{x}_0)(x_0-\bar{x}_0)^T]$. By employing the thinking logic of mathematical induction, we can derive the needed recursive formula.

Assume that we have obtained the observations up until time moment k: $y_1,\ldots,y_k$, and the optimal (unbiased) estimate $\hat{x}_k$ of the state x_k at time moment k. Before the next new measurement data value y_{k+1} becomes available, to estimate the state x_{k+1} at time moment k+1 we have to start with $\hat{x}_k$ by making use of the evolutionary rule described in eq. (2.5). Because w_k is a zero-mean white noise, we cannot know what value it takes. So, the most reasonable choice is let w_k=0, the mean value. On this basis, we obtain the predicted estimation as follows:

$$\hat{x}_{k+1|k}=\phi_{k+1,k}\hat{x}_k\,. \tag{3.1}$$

Because $Ew_k=0$, $E\hat{x}_k=Ex_k$, and $E\hat{x}_{k+1|k}=\phi_{k+1,k}E\hat{x}_k+T_{k+1,k}Ew_k=Ex_{k+1}$, we conclude that $\hat{x}_{k+1|k}$ is an unbiased estimate of x_{k+1}. So, an optimal estimation is provided by eq. (3.1). And by using the measurement expression in eq. (2.4) and by letting $v_{k+1}=0$ (for the same reason as above), we obtain the following predicted output value that corresponds to $\hat{x}_{k+1|k}$:

$$\hat{y}_{k+1|k}=H_{k+1}\hat{x}_{k+1|k}=H_{k+1}\phi_{k+1,k}\hat{x}_k\,. \tag{3.2}$$

At the time moment t=k+1, we immediately obtain the actual output value y_k+1 of the economic system. By comparing this actual value with the predicted value $\hat{y}_{k+1|k}$, we can compute the error of the predicted output:

$$\tilde{y}_{k+1|k}\triangleq y_{k+1}-\hat{y}_{k+1|k}=y_{k+1}-H_{k+1}\hat{x}_{k+1|k} \tag{3.3}$$

This expression includes not only the comprehensive information of the system's noise w_k, measurement noise v_k, filtering error, and other random variables, but also some new information about the state x_{k+1} as the measurement value y_{k+1} at time moment k+1 becomes available. Hence, let us refer to $\tilde{y}_{k+1|k}$ as a vector of new information (innovation). It is now natural for us to think about employing the new information at moment k+1 to correct the predicted state $\hat{x}_{k+1|k}$. That is, we can now derive a better estimate (filtering estimate) for the state at moment k+1. So, the estimation for the state at moment k+1 should consist of the following two parts: one is to derive the predicted estimate $\hat{x}_{k+1|k}$ of the state based on the observations up to time moment k, and the other is to correct the prediction $\hat{x}_{k+1|k}$ by employing the newly collected observation at moment k+1. When these two parts are put together, we establish our estimation for the state x_{k+1} at the time moment k+1. Symbolically, we have

$$\hat{x}_{k+1}=\hat{x}_{k+1|k}+K_{k+1}[y_{k+1}-H_{k+1}\hat{x}_{k+1|k}], \tag{3.4}$$

where K_{k+1} is referred to as a gain matrix or a correction factor. It is a real matrix. The key for our optimal filtering is to select correctly the gain matrix K_{k+1} so that the estimation $\hat{x}_{k+1}$ of the state obtained from eq. (3.4) has the minimum covariance matrix of error. That is, we have

$$P_{k+1} = E[(x_{k+1} - \hat{x}_{k+1})(x_{k+1} - \hat{x}_{k+1})^T] = \min . \qquad (3.5)$$

Next, we need to establish a formula from which we can produce the optimal gain matrix K_{k+1} that satisfies eq. (3.5) so that a complete recursive computational scheme can be developed for the purpose of estimating the state of movement of foreign capital within an economic system.

Let $\tilde{x}_{k+1} = x_{k+1} - \hat{x}_{k+1}$. Then the covariance matrix P_{k+1} of the filtering error can be written as $P_{k+1} = E[\tilde{x}_{k+1}\tilde{x}_{k+1}^T]$. From

$$\begin{aligned} \tilde{x}_{k+1} &= x_{k+1} - \hat{x}_{k+1} = x_{k+1} - [\hat{x}_{k+1|k} + K_{k+1}(y_{k+1} - H_{k+1}\hat{x}_{k+1|k})] \\ &= \tilde{x}_{k+1|k} - K_{k+1}[H_{k+1}x_{k+1} + v_{k+1} - H_{k+1}\hat{x}_{k+1|k}] \\ &= \tilde{x}_{k+1|k} - K_{k+1}[H_{k+1}\tilde{x}_{k+1|k} + v_{k+1}] \\ &= [I - K_{k+1}H_{k+1}]\tilde{x}_{k+1|k} - K_{k+1}v_{k+1} \end{aligned} \qquad (3.6)$$

where $\tilde{x}_{k+1|k} = x_{k+1} - \hat{x}_{k+1|k}$, it follows that

$$\begin{aligned} P_{k+1} &= E[\tilde{x}_{k+1}\tilde{x}_{k+1}^T] \\ &= E[((I - K_{k+1}H_{k+1})\tilde{x}_{k+1|k} - K_{k+1}v_{k+1})((I - K_{k+1}H_{k+1})\tilde{x}_{k+1|k} - K_{k+1}v_{k+1})^T] \\ &= [I - K_{k+1}H_{k+1}]E[\tilde{x}_{k+1|k}\tilde{x}_{k+1|k}^T][I - K_{k+1}H_{k+1}]^T + K_{k+1}E[v_{k+1}v_{k+1}^T]K_{k+1}^T \\ &\quad -[I - K_{k+1}H_{k+1}]E[\tilde{x}_{k+1|k}v_{k+1}^T]K_{k+1}^T - K_{k+1}E[v_{k+1}\tilde{x}_{k+1|k}^T][I - K_{k+1}H_{k+1}]^T \end{aligned}$$

Because $\hat{x}_{k+1|k} = \phi_{k+1,k}\hat{x}_k$ only depends on $\hat{x}_0$ and $y_1, y_2, \dots, y_k$, from the knowledge of statistics, it follows that $E[v_{k+1}\tilde{x}_{k+1|k}^T] = 0$ and $E[\tilde{x}_{k+1|k}v_{k+1}^T] = 0$. So, the formula for computing the covariance matrix P_{k+1} of the filtering error can be simplified as follows:

$$P_{k+1} = [I - K_{k+1}H_{k+1}]P_{k+1|k}[I - K_{k+1}H_{k+1}]^T + K_{k+1}R_{k+1}K_{k+1}^T , \qquad (3.7)$$

where $P_{k+1|k} = E[\tilde{x}_{k+1|k}\tilde{x}_{k+1|k}^T]$ is referred to as the covariance matrix of the prediction error, and $R_{k+1} = E[v_{k+1}v_{k+1}^T]$.

If we expand eq. (3.7) and regroup the terms, where, without causing confusion, we omit all the subscripts of H_{k+1}, K_{k+1}, and R_{k+1}, we have

$$\begin{aligned} P_{k+1} &= P_{k+1|k} + KHP_{k+1|k}H^TK^T - KHP_{k+1|k} - P_{k+1|k}H^TK^T + KRK^T \\ &= P_{k+1|k} + K(HP_{k+1|k}H^T + R)K^T - KHP_{k+1|k} - P_{k+1|k}H^TK^T \end{aligned} \qquad (3.8)$$

Our purpose here is to derive the gain matrix K such that P_{k+1} reaches its minimum. Therefore, we rewrite eq. (3.8) as a complete square, such as the form of $(KS - A)(KS - A)^T$. Because

$$(KS - A)(KS - A)^T = KSS^TK + AA^T - KSA^T - AS^TK^T , \qquad (3.9)$$

By comparing eq. (3.9) and (3.8), we can see that because $HP_{k+1|k}H^T$ is a non-negative definite matrix and R is positive definite, $HP_{k+1|k}H^T + R$ is a positive definite matrix. So, from matrix theory [4], it follows that each positive definite matrix can be expressed as the square of a certain symmetric positive definite matrix. So, let us assume

$$HP_{k+1|k}H^T + R = SS^T \tag{3.10}$$

where S is a symmetric positive definite matrix. Next let $SA^T=HP_{k+1|k}$, where matrix A actually exists because the square matrix S is of full rank.

By substituting eqs. (3.9) and (3.10) into eq. (3.8) we obtain the following:

$$\begin{aligned} P_{k+1} &= P_{k+1|k} - KSS^T K^T - KSA^T - AS^T K^T \\ &= P_{k+1|k} + (KS-A)(KS-A)^T - AA^T \end{aligned} \tag{3.11}$$

From eq. (3.11), we see that only the second term on the right hand side has something to do with the gain matrix K, while this term is a non-negative definite matrix. Hence, to make P_{k+1} reach its minimum, we only need to select such a matrix K so that the second term in eq. (3.11) is equal to zero. So, we have

$$\begin{aligned} K &= AS^{-1} = P_{k+1|k}H^T S^{-T} S^{-1} = P_{k+1|k}H^T (SS^T)^{-1} \\ &= P_{k+1|k}H^T (HP_{k+1|k}H^T + R)^{-1} \end{aligned} \tag{3.12}$$

If we select K according to eq. (3.12), then the covariance matrix P_{k+1} of the filtering error is

$$\begin{aligned} P_{k+1} &= P_{k+1|k} - AA^T = P_{k+1|k} - AS^{-1}HP_{k+1|k} \\ &= P_{k+1|k} - KHP_{k+1|k} \\ &= (I-KH)P_{k+1|k} \end{aligned} \tag{3.13}$$

Next, let us derive a computational formula for the covariance matrix $P_{k+1|k}$ of the prediction error. From the formula for $P_{k+1|k}$, it follows that

$$\begin{aligned} P_{k+1|k} &= E[\tilde{x}_{k+1|k}\tilde{x}_{k+1|k}^T] = E\{[\phi_{k+1|k}\tilde{x}_k + T_{k+1,k}w_k][\phi_{k+1|k}\tilde{x}_k + T_{k+1,k}w_k]^T\} \\ &= \phi_{k+1,k}E[\tilde{x}_k\tilde{x}_k^T]\phi_{k+1,k}^T + T_{k+1,k}E[w_k w_k^T]T_{k+1,k}^T \\ &= \phi_{k+1,k}P_k\phi_{k+1,k}^T + T_{k+1,k}Q_k T_{k+1,k}^T \end{aligned} \tag{3.14}$$

By combining what is obtained above, for the system in eq. (2.5), we have obtained all the recursive formulas necessary for estimating the state of movement of foreign capital within the economic system. However, to employ this theory to practically estimate the magnitude of foreign capital’s investment, regional distribution, and differences between industries within the economic system at any chosen time moment, we still need to estimate the initial state.

4. ESTIMATE THE INITIAL STATE OF FOREIGN CAPITAL’S MOVEMENT

From our discussions above, it follows that once we have the knowledge of the initial state of the movement of foreign capital within the economic system of our concern or a good estimation of that initial state, we then can estimate the state of foreign capital’s movement system step by step. To this end, the general method is to determine the initial state $x(0)$ by using the prior (known) knowledge and then calculate the initial covariance matrix $P(0)$ by employing the degree of accuracy of $x(0)$. In this section, we assume that we have the initial observations at time moments t_1 and t_2. We then roughly estimate the state of the foreign capital’s movement system at moment t_2 and its variance. These values will be used as the initial state of foreign capital’s movement within the economic system. In particular, assume that the initial two observations are respectively

$y(1) = [y_1(1), y_2(1), y_3(1)]^T$ and $y(2) = [y_1(2), y_2(2), y_3(2)]^T$.

Then we calculate the following estimation of the initial state:

$\hat{x}(0) = [\hat{x}_1(0), \hat{x}_2(0), \hat{x}_3(0), \hat{x}_4(0), \hat{x}_5(0), \hat{x}_6(0)]^T$,

where

$$\hat{x}_{2i-1}(0) = y_i(2),\ \hat{x}_{2i}(0) = [y_i(2) - y_i(1)]/T,\ i = 1, 2, 3, \tag{4.1}$$

and

$$P(0) = E[(x_2(0) - \hat{x}(0))(x_2(0) - \hat{x}(0))^T] = \begin{bmatrix} P_1(0) & & \\ & P_2(0) & \\ & & P_3(0) \end{bmatrix},$$

where

$$P_i(0) = \begin{bmatrix} R_i(2) & R_i(2)/T \\ R_i(2)/T & [R_i(1) + R_i(2)]/T^2 \end{bmatrix},\ i = 1, 2, 3, \tag{4.2}$$

In the following, we use a sub-matrix $P_1(0)$ as an example to illustrate the detailed steps of computation.

Because $\hat{x}_1(0) = y_1(2) = x_1(2) + v_1(2)$, we have

$$\begin{aligned} \hat{x}_2(0) &= [y_1(2) - y_1(1)]/T \\ &= [x_1(2) + v_1(2) - x_1(1) - v_1(1)]/T \\ &= \{[x_1(2) - x_1(1)] + [v_1(2) - v_1(1)]\}/T \end{aligned}$$

Because $x_2(2) = [x_1(2) - x_1(1)]/T$, we have

$$x_1(2) - \hat{x}_1(0) = -v_1(2),\ x_2(2) - \hat{x}_2(0) = -[v_1(2) - v_1(1)]/T$$

$$\begin{aligned} P_1(0) &= E\left\{ \begin{bmatrix} x_1(2) - \hat{x}_1(0) \\ x_2(2) - \hat{x}_2(0) \end{bmatrix} \begin{bmatrix} x_1(2) - \hat{x}_1(0) \\ x_2(2) - \hat{x}_2(0) \end{bmatrix}^T \right\} \\ &= E\left\{ \begin{bmatrix} -v_1(2) \\ -[v_1(2) - v_1(1)]/T \end{bmatrix} \begin{bmatrix} -v_1(2) \\ -[v_1(2) - v_1(1)]/T \end{bmatrix}^T \right\} \\ &= \begin{bmatrix} R_1(2) & R_1(2)/T \\ R_1(2)/T & [R_1(1) + R_1(2)]/T^2 \end{bmatrix} \end{aligned}$$

Similarly, we can obtain the other sub-matrices of eq. (4.2).

As of this point in our presentation, we have established a complete theory on how to estimate the state of movement of foreign capital within the economic system. And on the basis of the estimations, we can design appropriate strategies and measures to counter the adverse effects of foreign investments while insuring the economic security of the economic system.

5. HOW DISTURBANCES OF FOREIGN CAPITAL AFFECT ECONOMIC SECURITY

Because of the entry of foreign capital, the money supply within the receiving economic system is increased, making the system have additional resources to produce so that the economic strength of the system consequently grows rapidly. However, with the accumulation of foreign capital to a large magnitude, when the foreign capital suddenly withdraws, a severe shock to the economic activities of the economic system will be created. For example, let us look at a fictitious economic system whose financial system is open to the outside world. Assume that at a certain time moment, the nation's total money supply is $50,000, including domestically invested foreign capital of $7,500. That is, the foreign investment occupies 15% of the entire national money supply. With the additional money supply, as created by the foreign capital, the circulation speed of money within the economic system accelerates, which indicates that this nation spends more on various economic activities and on the promotion of its economic level. If at a later time moment the capital invested by foreign merchants is suddenly withdrawn from the economic system, then it will inevitably, to a great extent, cause the liquidity of money within the economic system to drop suddenly, affecting adversely over 15% of all the economic activities within the economy. Hence, the economic system has to strengthen the monitoring of foreign capital in order to prevent the disastrous aftermath created by the currency war into which the initial friendly investment was evolved by sudden large scale withdraw. The essential reason why an economic system introduces foreign capital is to stimulate its economic development. That is to say, there is a pre-defined purpose within the economic system for how the entering foreign capital will develop. This pre-defined purpose is referred to as the ideal trajectory of the movement of foreign capital. On the other hand, the fundamental reason for foreign capital to enter the economic system is to make profit, which includes taking advantage of the promised preferential conditions, low-priced resources available from within the economic system, developing the market resources of the new economy, etc. In the process of materializing the desired profit, the actual state of movement of foreign capital most likely deviates from the ideal trajectory that is pre-defined by the economic system. When such deviation expands, it might gradually erode the economic security of the economic system that is additional to the significant damage that might occur to the economic system when a collective withdraw of foreign capital happens at certain time moment. Based on what has been discussed and analyzed earlier, the economic system could acquire "truthful estimations" of the state of domestic movement of foreign capital and possible trends of future development. So, for the policy makers of the economic system, they must design and introduce a series of policies to guide the "truthful estimations" to approach the ideal trajectory in order to materialize the desired control of the adverse effect of foreign capital on the economic security of the economic system. Such dynamic adjustment on the part of policy makers could also potentially prevent a currency war created by large scale sudden withdraws of foreign capital although the capital initially entered the economic system in friendly terms.

When applying a strategy to regulate the state of movement of foreign capital, it is inevitable that some of the limited resources of the economic system will have to be occupied and exhausted. So, a control strategy is considered ideal if it could not only reach its purpose of control within a limited time interval but also consume as little amount of resource as possible. To this end, as a form of expression for energy consumption, quadratic functions will be used due to their excellent properties. These functions can describe not only how resources are wasted by implementing excessive control, but also the distance from the target as caused by insufficient control. Therefore, in the following, we will choose a quadratic function as our evaluation standard to measure control strategies.

Let us define the objective function as follows:

$$J_N = \sum_{k=0}^{N-1}[(\hat{x}(k+1) - \bar{x}(k+1))^T Q(k)(\hat{x}(k+1) - \bar{x}(k+1)) + u(k)^T R(k)u(k)]$$

where N stands for the final time moment when the actual state $x(N)$ could approach the pre-defined ideal state $\bar{x}(N)$ "perfectly", $Q(k)$ the effect on the economic system as caused by the difference between the "truthful estimation" and the "ideal trajectory" at moment k, $R(k)$ the price that has to be paid for adopting control strategy $u(k)$ at moment k.

Because this objective function contains the effect on the economic system of the difference between the "truthful estimation" and the "ideal trajectory" and the price paid to implement the control strategy u, the policy makers should design an optimal control strategy that makes the previous objective function reach its minimum. However, the design of any policy strategy is constrained by the resources available within the economic system, that is, $u(k)\in\Omega$, where Ω stands for the space of constraints of all strategies. So, the purpose of the entire control problem is to find a control sequence $u^*(k)\in\Omega$ such that

$$J(u^*(0), u^*(1), \cdots, u^*(N-1)) = \min_{\Omega} J_N$$

Because the effect of policies can lead to changes in the state of foreign capital movement system, the "truthful estimation" $\hat{x}(k+1)$ is a function of policy $u(k)$. According to the necessary conditions for a function to reach its extreme values, we have

$$\frac{\partial J_k}{\partial u_k} = 0 .$$

That is,

$$Q(k)(\hat{x}(k+1) - \bar{x}(k+1))^T \frac{\partial \hat{x}(k+1)}{\partial u(k)} + R(k)u(k) = 0$$

So, we have

$$u(k) = -R^{-1}(k)Q(k)(\hat{x}(k+1) - \bar{x}(k+1))\frac{\partial \hat{x}(k+1)}{\partial u(k)}$$

Theoretically speaking, the feasible region of the constraint variables is bounded, the objective function is nonnegative and convex. Therefore, generally there is an optimal control sequence $u^*(k)\in\Omega$ such that J_N reaches its minimum. However, because it is difficult to quantitatively or analytically describe the feasible region of the constraint variables, it is also difficult to provide a formal expression for an optimal strategy. Even so, we will try to develop a general description of the necessary control strategy by using the state equation and possible evolution tendencies of foreign capital movement within the economic system combined with the systemic yoyo model. Therefore, in the following we will provide several strategies based on logical analysis and reasoning strategies that could counter disturbances caused by foreign capital within the economic system and protect the economic security of the system in order to avoid the disastrous aftermath of the currency war that occurs along with large scale withdraw of foreign capital that was initially invested within the system in friendly terms.

First, moderately monitor and supervise the activities of foreign investments, and strengthen the control of foreign capital if it attempts to enter the virtual economy, such as the financial market, stock market, etc. Although the assets of foreign capital that enters the virtual economy could provide investment capital for the economic system, such capital can often perturb the operation of the domestic financial system through unconventional ways, disrupt the smooth operation of the system, and withdraw from the system as soon as a high rate of return is acquired within a short period of time by making use of its scale and other advantages. Such short-term rapid movement of capital can cause turbulence to the otherwise normal operation of the domestic financial market of the economic system, which in practice materializes damage to the domestic financial system. The Southeast Asian financial storm of the year of 1998 was an example of how foreign capital acquired short-term high rates of returns by making use of the imperfections of the regional financial systems. This financial storm ransacked the economic achievements of the past several decades of the relevant regions within a short time period, while leaving the development of these economies on the verge of collapse [3]. Therefore, the receiving economic system must strengthen its supervision of those foreign capital investments that intend to enter the domestic financial market or the virtual economy, crackdown any illegal entry behaviors of foreign capital, and improve the control mechanism over the foreign capital that flows into any of the non-real economies. At the same time, receiving economic systems must constantly perfect emergency plans and formulate control measures for temporary, abnormal capital movements by considering the potentially most severe scenarios based on the logic of balancing the abnormal inflow and outflow of foreign investment capital.

Second, implement a flexible exchange rate mechanism in order to maintain investment grade foreign capitals while expelling those that are speculative in nature. Among all the capital of foreign investments, the portion that enters into the real economy is the one needed by the domestic economic system for its economic development. This capital intends to acquire relatively long-term profits by valuing the development potential of the economic system and by actively investing in the economic system. On the other hand, this capital could be relied on for the construction and development of the real economy and for its relatively long-term stay within the economic system. However, the entry of the speculative portion of foreign capital into the domestic economic system is mainly for the purpose of obtaining speculative profits by making use of the imperfections that exist in the market place and the financial system of the receiving economy. Hence, the economic system should employ its flexible exchange rate mechanism to discourage the influx of such foreign capital and to convert the influx of such foreign capital into investments in the real economy. For example, assume that merchant C is an international speculator and that he is upbeat about the stock market of the particular economic system and enters the stock market with an amount of US$1 billion. If the exchange rate between the U.S. dollar and the domestic currency is 1:5, then his entry into the stock market represents 5 billion units of the local currency. After obtaining a short-term speculative profit in the stock market, C wants to close out his positions. If at this time moment the monetary authority of the economic system has somehow changed the exchange rate to 1:6 by making use of their flexible exchange rate policy, then C's original speculation amount of 5 billion units of the local currency can only be converted to US$5/6 billion = US$0.833 billion, where US$0.167 billion has evaporated. That is, the flexible exchange rate mechanism has discouraged C's speculation in the stock market, while the short-term varying exchange rate has little adverse effect on the foreign capital that is invested in the real economy. Hence, when a relatively large amount of foreign capital enters into the economic system, the receiving economy could employ a flexible exchange rate mechanism to discourage speculative capital while retaining the capital that is invested in the real economy.

Third, implement a flexible foreign investment policy to guide foreign investment capital into the target industries and geographic regions by making use of the economic system's market demand, cost advantage, and other resources. The profit-driven characteristics of foreign capital determine where and which industries foreign capital will enter; from how foreign capital flows into the economic system to obtain its desired profit, the investment types of foreign capital can generally be classified into the following five categories: cost seeking, policy seeking, resource seeking, market seeking, and technology seeking. With increasing economic strength of the economic system, the accumulation of investment capital, and the rising of labor cost, the foreign invested enterprises of policy-seeking and cost-seeking types, and some of the market-seeking types with relatively weak competitiveness will have to leave the economic system or remake themselves into different types, while those foreign capital assets of market-seeking and technology seeking types might very well occupy the high end positions of their individual markets and supply chains. Hence, the receiving economic system of foreign capital should sufficiently utilize its consumer market and related fundamental advantages, such as opening its domestic market, already established supporting industries, existing resource conditions, etc., to guide the investment capital of market-seeking, technology seeking, and other types into the high technology areas that are needed by the development of the economic system. These investments will not only stay within the economic system for the long term, but also strengthen their collaboration with the economic system and improve the position of the economic system within the machining and manufacturing chain. Additionally, by making use of the differences between investment policies internal to the economic system, such as the various preferential policies in terms of taxation, land use, regulations, etc., as introduced by different regions with varying degrees of capital scarceness, the receiving economic system could direct the foreign invested enterprises of policy-seeking and cost-seeking types, and some of the investment assets of market-seeking type with less competitiveness to migrate into regions with less foreign investment capital. These different investment policies could also be used to improve the uneven investment distribution within the economic system while decreasing the disparity between the development gradient forces of different regions.

Last, promote the capability of innovation and creativity of the enterprises within the economic system and the public of the entire society. According to the systemic yoyo model, the competition between foreign capital and domestic business entities makes some domestic firms been absorbed by foreign capital, while some others been pushed and pulled (or bullied), where some of these bullied entities grow with the intensified competition and eventually become able competitors while some others are eliminated out of the existence. Those economic organizations that are either absorbed by foreign capital or eliminated are mainly those that are less competitive, and the competitiveness of an organization is mainly originated from the organization's creativity. When an economic organization possesses a strong capability of innovation, the yoyo field of this organization has a strong force of attraction and a steady ability to stand and take shocks from the environment. That strong capability of innovation can help promote the magnitude of the organization's yoyo field, while carrying the field to a higher level. As soon as the magnitude of the yoyo field of the organization rises to a new level, it would generally have acquired additional energy to better counteract the attraction and pressure of the yoyo field of foreign capital, while it might conversely absorb the yoyo field of foreign capital and make this external field a part of itself. In other words, improving the endogenous creativity is the fundamental way for the economic system to increase the magnitude of its yoyo field. To this end, the economic system can improve its internal innovation environment by fostering a good atmosphere for innovation, increasing investment in innovation, encouraging innovative behaviors, and providing innovators with conditions to materialize their creativities. On top of all these suggested remedies the economic system would be able to reach a new level of creativity of the entire society.

6. CONCLUDING REMARKS

Because foreign capital can adversely affect the security of the receiving economy [3,7], this paper addresses the following challenging question: While taking advantage of foreign investments, how can a nation protect itself against the potential disastrous aftermath in case some of the foreign investments were actually part of an active currency war against the nation?

To this end, this paper establishes a theoretical model for monitoring the movement and dynamics of foreign capital within a nation's economy. Then potential measures that are useful for countering the adverse effects of foreign investments on the national economy are developed.

REFERENCES

[1] Cheng, L.K. & Kwan, Y.K. (2000). What are the determinants of the location of foreign direct investment? The Chinese experience. *J. Int. Economics*, 51, 379-400.

[2] Cinlar, E. (2013) *Introduction to Stochastic Processes (Reprint edition)*, New York, NY: Dover Publications.

[3] Forrest, J. (2014). *A Systems Perspective on Financial Systems*, New York, NY: CRC Press, an imprint of Taylor and Francis.

[4] Horn, R.A. & Johnson, C.B. (2012). Matrix Analysis (2nd edition), Cambridge, UK: Cambridge University Press.

[5] Lin, Y. (2008). *Systemic Yoyo Model: Some Impacts of the Second Dimension*, New York, NY: Auerbach Publications, an imprint of Taylor and Francis.

[6] Liu, S.F. & Lin, Y. (2006). *Grey Information: Theory and Practical Applications*, London, UK: Springer.

[7] Schimmel, K., Liu, S.F., Nicholls, J. & Forrest, J. YL. (2017). Effects of foreign capital on economic security, *Advances in Systems Science and Applications*.

