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A Novel Method of Finance Market Regulation Based on Control Overshoot

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Abstract In the finance market, risk happened in two pattern. In one case, extreme volatility together with a short balance time leads to a great panic to the market. On the contrary, if the volatility is smaller, the time period will usually be longer. It will bring many infections to various related fields, which causes wider range influences to the economy. Both cases hurt financial market and the economy itself deeply. In this paper, we developed a novel market regulation method in which the conflict of fluctuation time and volatility will be balanced. It describes a way to compute a portfolio of relatively short time period together with smaller fluctuation volatility by using a general prediction algorithm based on overshoot in cybernetics. It can also give explanation to counter-cyclical supervision theory and macro-prudential regulation. Furthermore, it can provide numerical operation guide for counter-cyclical supervision theory and macro-prudential regulation.

Keywords control overshoot; finance regulation; general predication method; soften factor; compensation mechanism

1 Introduction

Recurrent dramatic upward and downward movements of international finance market raised the question that whether our risk management methods are still working well, especially in many Asia markets, which have accumulated systematic risks inherently. Because of the political and economic reason, volatilities in different world stock markets are more likely to be larger and larger. Now, similar worries emerged in recent foreign exchange markets. Comprehensive historical accounts of such phenomena and their macroeconomic consequences are provided by many researchers[1–4]. Though there are many ones who support that completely free market can overcome the fatal shortcomings in different financial markets, the reality is that more

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and more countries chose to construct professional independent authority specially serving for finance security and systematic risk management. Actually, financial markets have instability inherently. For some financial markets that have lower degree of openness, regulations by central banks or governments are used frequently. Furthermore, they have already been proved to be very effective ways in many markets. As the market risk patterns are keeping changing, authorities need more qualitative and quantitative macro tools besides macro-prudential policy and counter-cyclical regulations to manage the fluctuation in the finance market[5].

Therefore, the crucial questions are accordingly what kind of tools and mechanisms may be applied to control the volatility of the finance market. In most cases, in order to control volatility into a small value, system will use much longer time process than usual to digest the risk. Consequently, since finance market is the center of the whole economy, in the time process, it causes infection to many other related fields and leads to a wider range risk[6]. In other cases, risk appeared and happened in a relatively shorter time, but it leads to extreme risks with fat-tail distributions and together with more larger volatility. That may cause very bad influence to economy. Both of them hurt the development of finance market and economy itself. Apparently, we need to put more emphasis on how to slow down the occurrence of risks, and balance the volatility value with a possible rational time process. In the practice of financial regulation, the portfolios of values of time process and volatility under different circumstances are called the set of steady states. Hence, in this paper, we focus on how to control values of both time period and volatility, and find the steady state.

Because financial market development will influence the strategy and openness degree of a country or a district. Both banking institutions and economic entities invested a remarkable amount of researches on the pricing mechanism and risk management. In the study of financial security, what is secure and how to realize the security are problems that always puzzle the theory and practice circle. How to fully utilize and develop financial derivatives market in the premise of guaranteeing financial security is becoming the hot and difficult topic of the research. It is important to keep in mind that risk is the opportunity of financial market, and regulations are expected to keep the amplitude in a certain range and smooth the fluctuations, not to diminish it. At the same time, financial crisis reminds us that the vulnerability of the financial system can never be ignored[7]. As we can see, financial systems is experiencing various shocks everyday, such as the stock market in China which built up the circuit breaker mechanism, but ends up with the flood criticisms. There are overshoots in all financial systems, but the degrees are varied and fast-changing. Objectively, financial system must have the ability to undertake more than its average load. Otherwise the system is very easy to be broken and too fragile.

There are many researches on risk management, some of which focused on the risk's derivative procedure[8–11]. Most researches mainly focus on the different types of risk management for the institutions. But for the risk of finance market as a whole, researches are rather less. Our model differs in several respects from the existed papers. In this paper, the focus is to make the financial market safer in the dimension of time and frequency domain, by using the method of overshoots in control theory. Firstly, we put forward the method on overshoot. Secondly, we use a prediction method to balance the time period and the fluctuation. At last, we show the effect of the method by simulating it.

2 Method

Though there is rated load for each system, overshoot is still very important for all the systems. Most systems have overshoot, but financial systems need more overshoot than other systems, because the systems are all operating with high frequency fluctuations, and undertaking more fluctuations than the average load everyday. Therefore, allowing a certain proportion of overshoot is critical for the robustness of financial system. Proper overshoot not only enhances the stability of the system, but also provides more flexibility to the system. It helps to balance different types of system including financial markets with more steady states than the average systems.

2.1 Computation of Overshoot

Overshoot is one of the dynamic performance indicators of control system. Dynamic performance indicators are those who have the values of zero in the initial condition. By inputting step-function signal, the response of the system is defined by a set of indicators which describe properties of the system.

In signal processing, control theory, electronics, and mathematics, overshoot is the occurrence of a signal or function exceeding its target. It arises in the step response of bandlimited systems such as low-pass filters. It is often followed by ringing, and at times conflated with the latter. Overshoot refers to an output exceeding its final, steady-state value. For a step input, the percentage overshoot (PO) is the maximum value minus the step value divided by the step value. In the case of the unit step, the overshoot is just the maximum value of the step response minus one. Also see the definition of overshoot in some electronics contexts.

Here, the percentage overshoot is a function of the damping ratio ζ, and it is given by

$$PO = 100 \cdot \mathrm{e}^{\frac{-\varsigma\pi}{\sqrt{1-\varsigma^2}}}. \tag{1}$$

The damping ratio can also be found by

$$\varsigma = \sqrt{\frac{(\ln \frac{PO}{100})^2}{\pi^2 + (\ln \frac{PO}{100})^2}}. \tag{2}$$

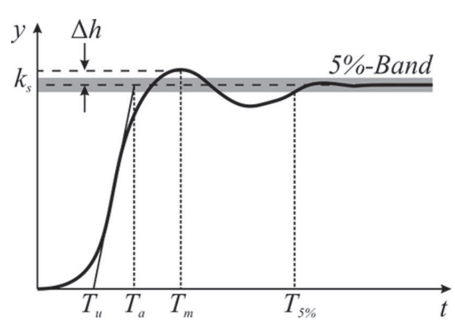

Figure 1 Overshoot control

Prediction control algorithm is the method mainly used in auto control system to realize the overshoot adjustment. After thirty years' development, model control algorithm, dynamic model control algorithm and general prediction control algorithm appeared. Among them, the general prediction algorithm became very popular in the application of system control and process control in recent years. It has the advantage of both prediction control and self adaptive control. The differences of various algorithms are mainly in that how to restrain the amplification of overshoot effectively and how to control the time period of the control procedure.

General prediction algorithm (GPA) model is set up based on CARIMA model which is based on non-stationary noisy procedure. It is described as

$$A[z^{-1}]y[k] = B[z^{-1}]u[k-1] + C[z^{-1}]\xi[k]/\Delta, \tag{3}$$

where $u[k]$ is the system input and $y[k]$ is the system output.

$\xi[k]$ is a sequence which is irrelevant to each other, and the expectation of this sequence is 0, which means it is a white noise.

Δ is a differential operator, we can write it as $\Delta = 1 - z^{-1}$; where $A[z^{-1}] = 1 + a_1 z^{-1} + \cdots + a_{n_a} z^{-n_a}$ and $B[z^{-1}] = 1 + b_1 z^{-1} + \cdots + b_{n_b} z^{-n_b}$. Thus, if $C[z^{-1}] = 1$, then when at the time $k + j$, in the process above, the output result of prediction control is like

$$y(k+j/k) = \overline{G}_j(z^{-1})\Delta u(k+j-1) + S_j(z^{-1})y(k) + R_j(z^{-1})\xi(k+j), \tag{4}$$

where

$$\begin{aligned}
&\overline{G}(z^{-1}) = R_j(z^{-1})B(z^{-1}),\\
&R_j[z^{-1}] = 1 + \sum_{i=1}^{j-1} r_{j,z} z^{-1},\\
&S_j[z^{-1}] = \sum_{i=0}^{n_a} s_{j,z} z^{-1}.
\end{aligned}$$

Since $\xi[k]$ is an irrelevant noise sequence with zero expectation. Then, at time $k + j$, the optimal prediction is expressed as

$$y(k+j/k) = \overline{G}_j(z^{-1})\Delta u(k+j-1) + S_j(z^{-1})y(k), \tag{5}$$

where $j = 1, 2, \cdots P$, P is the maximum valid step of the process.

For the performance indicators of the process above, we weight the output of the algorithm and error control increment quadratic performance index as following:

$$J_p = \sum_{j=N_1}^{P} q_j[y(k+j) - y_r(k+j)]^2 + \sum_{j=1}^{M} \lambda_j[\Delta u(k+j-1)]^2, \tag{6}$$

where N_1 is the minimum value of the prediction length. This value for the delay is known to the system, and the system need to have an ability to cover it, that value can not be smaller than the delay, so that the model will be able to apply.

M is the length of control time domain. q, λ, which denote the weight of error term and the weight to quadratic of control process increment respectively, are weighting variables. Especially, $y_r(k+j)$ is a soften factor in a specific default value, which is shown as a soft track accordingly.

Our purpose is to make the output be as accurate as possible to the default value we set in the operation of the system. The default value is expressed as ϖ. To achieve this, by using first-order filter equation as following, we filtered the process.

$$y_r(k+j) = \alpha y_r(k+j-1) + (1+\alpha)\varpi. \tag{7}$$

Let $y_r(k) = y(k)$. Then, it became a problem to get the minimum solution of J_p.

In order to have the minimum value of J_p, matrix solution of input process of system is expressed as follows:

$$\Delta U(k) = [G^{\mathrm{T}}QG + \lambda I]^{-1}G^{\mathrm{T}}Q \times [Y_r(k+1) - F_0\Delta U(k-1) - S(z^{-1})y(k)], \tag{8}$$

where

$$\begin{aligned}
&Y(k+1) = [y_r(k+1), \cdots, y_r(k+P)]^{\mathrm{T}},\\
&\Delta U(k) = [\Delta u(k), \cdots, \Delta u(k+M-1)]^{\mathrm{T}},\\
&\Delta U(k-1) = [\Delta u(k-n_b), \cdots, \Delta u(k-1)]^{\mathrm{T}},\\
&G = \begin{bmatrix} g_{1,0} & & & \\ g_{2,1} & g_{1,0} & & \\ \vdots & \vdots & & \\ g_{P,P-1} & g_{P-1,P-2} & \cdots & g_{P-M+1,P-M} \end{bmatrix}_{P\times M},\\
&F_0 = \begin{bmatrix} g_{1,n} & g_{1.n-1} & \cdots & g_{1,0} \\ g_{2,1} & g_{1,0} & & g_{1,1} \\ \vdots & \vdots & & \vdots \\ g_{P,P-1} & g_{P-1,P-2} & \cdots & g_{P-M+1,P-M} \end{bmatrix}_{P\times M},\\
&Q = \mathrm{diag}(q_1, q_2, \cdots, q_n),\\
&\lambda = \mathrm{diag}(\lambda_1, \lambda_2, \cdots, \lambda_n).
\end{aligned}$$

In general, in the process of computing $\Delta U(k)$, the increment is the focus of system control process. Consequently, we use interception vector $f = [1, 0, \cdots, 0]_{1\times M}$, by multiplying the interception vector and input vector of control process, we have the control increment of current time $\Delta u(k) = f \times \Delta U(k)$, furthermore, we can get the control value of current state as

$$u(k) = u(k-1) + \Delta u(k). \tag{9}$$

The method above expresses the process we use to amend and promote the system operation. We actually extracted a control procedure frame for regulatory authority. This is an arithmetical expression of financial regulation and supervision pattern, which forms the base of our regulation pattern research. In the following, we will analyze the application of overshoot conception group in finance market, and give out a new perspective from cybernetics theory to solve the problem of the systematic risk.

3 Algorithm

In GPA, there is a soften factor, which will constraint the increment value produced in the operation of system by the input. It is just the advantage of GPA which made us to apply it in the management of finance market.

Let the soften coefficient $\beta \in [0,1]$, then the increment at time $k+j$ is expressed as:

$$\Delta u[k+j] = \sum_{i=0}^{j} \beta^i \Delta u[k], \quad j = 0, 1 \cdots, M-1, \tag{10}$$

$$\Delta U(k) = \left[1, 1+\beta, \cdots, \sum_{i=0}^{M-1} \beta^i\right]^{\mathrm{T}} \times \Delta u[k]. \tag{11}$$

Since the restriction to the soften factor has already produced its constraint to control increment, so we can let other constraint items in J_P to be $\lambda_j = 0$, and let $q_j = 1$. Thus, to solve the problem of minimum solution of J_p has been transferred into the objection function as following

$$J_P = [Y(k+1) - Y_r(k+1)]^{\mathrm{T}} \times [Y(k+1) - Y_r(k+1)], \tag{12}$$

where $Y(k+1) = [y(k+1), \cdots, y(k+p)]^{\mathrm{T}}$.

In the process of getting the optimal solution of J_P, we obtain the control increment of system process as follows:

$$\Delta u(k) = [G_2^{\mathrm{T}} G_2]^{-1} G_2^{\mathrm{T}} \cdot [Y_r(k+1) - F_0 \Delta U(k-1) - S(z^{-1}) y(k)], \tag{13}$$

$$G_2 = G \times H,$$

$$H = \left[1, 1+\beta, \cdots, 1 + \sum_{i=1}^{M-1} \beta^i\right]^{\mathrm{T}}.$$

$G_2^{\mathrm{T}} G_2$ is a scalar value, so we don't need to calculate the matrix and the inverse. In the same way, the current control value can be obtained as $u(k) = u(k-1) + \Delta u(k)$, which is used to control the input.

To control the input, we adjust it by using the track of $y_r(k+P)$. Because we have already set ϖ as the target value, in the operation process, when the output is approaching the target we set, it is certain that the combination of fast response speed and very high overshoot appears. The system will achieve balance in a very short time. If the system cannot bear the fluctuation, that may cause some trouble or even break the system. In order to realize the fast response with lower overshoot, we need to adjust the fluctuation amplitude to be acceptable to the system. We named this procedure as the compensation mechanism. The key point of this mechanism is that using the increment of next moment to compensate the control value of current moment.

According to our deduction, the input of next moment $\Delta u(k)$ will be computed under the condition that J_p is the optimal solution. And the next moment increment can be computed by the previous increment and next moment input, by using the soften track already set, the next time increment is deduced.

$$\Delta u(k+1) = [G^{\mathrm{T}} G]^{-1} \cdot [Y'(k+1) - F_0 \Delta U'(k-1) - S(z^{-1}) y(k+1)], \tag{14}$$

where

$$\begin{aligned}
&Y'[k+1] = [y_r'[k+1], \cdots, y_r'[k+P]]^{\mathrm{T}},\\
&y_r'(k+j) = \alpha y_r'(k+j+1) + (1-\alpha)\overline{\omega},\\
&y_r'(k+j) = y_r(k+1),\\
&\Delta U'(k-1) = [\Delta u(k-n_b+1), \cdots, \Delta u(k)]^{\mathrm{T}}.
\end{aligned}$$

In the same way, by using the procedure above, we can get a value that approximately equals to $y(k+j)$. This estimated value is called $y_p(k+j/k)$, which will be the substitution for $y(k+j)$ to compute in $\Delta u(k+1)$. Abbreviating the procedure, now we set control domain as $M=1$, and do the prediction of control increment for p steps.

Since

$$\Delta u(k+2) = \Delta u(k+3) = \cdots = \Delta u(k+P) = 0. \tag{15}$$

For $y(k+j/k) = \overline{G}_j(z^{-1})\Delta u(k+j-1) + S_j(z^{-1})y(k) + R_j(z^{-1})\xi(k+j)$.

We have

$$\begin{aligned}
y_p(k+j/k) = {}& g_{P,P-1}\Delta u(k+1) + \cdots + g_{P,P}\Delta u(k) + \cdots + g_{P,n_b+P-1}\Delta u(k-n_b+1)\\
&+ F_P(z^{-1})\Delta u(k+1) + S_P(z^{-1})y'(k+1),
\end{aligned} \tag{16}$$

where

$$\begin{aligned}
&F_P(z^{-1}) = g_{P,P-1} + \cdots + g_{P,P}z^{-1} + \cdots + g_{P,n_b+P-1}z^{-n},\\
&J_p = q[y_p(k+P)/k - y_r(k+P)]^2 + \lambda\Delta u(k)^2.
\end{aligned}$$

Similarly, we can obtain

$$\Delta u(k+1) = [y_r(k+P) - S_P(z^{-1})y'(k+1)] \times \frac{1}{F_P(z^{-1})}. \tag{17}$$

This is the control increment we need in the next moment. By compensating the next moment control increment in previous, we can control the overshoot of system. In this procedure we will get the control value that can be used to coordinate overshoot and response time. It can be expressed as follows:

$$u^0(k) = u(k) + \theta\Delta u(k+1). \tag{18}$$

In this expression, the coefficient θ is a compensation coefficient. Actually, it is not necessary to compensate the system completely. As we mentioned, each system will have a certain ability to be overloaded. So for most cases, we only need to compensate the next moment partly, especially when it is related to the finance market. Huge capital investment is needed even for a very small portion of adjustment. So if partly compensation works, we don't necessarily need compensate it completely. That means the mechanism here is flexible. The input after being compensated is an adjustment to the operation of system in previous. The purpose to do adjustment is to get an ideal balance for the response time and overshoot, which leads the system to balance itself with a portfolio of system process having smaller fluctuation and shorter time simultaneously.

To make it easier, we can express the computation procedure briefly as following:

Step 1: Compute input factor $\Delta u(k)$ and $u(k)$.

Step 2: Solve the equation and get approximation value of $y(k+j)$, express as $y_p(k+j/k)$.

Step 3: Get the solution for next moment compensation value $\Delta u(k+1)$.

Step 4: Compensate $\Delta u(k+1)$ to $u(k)$, partly or totally.

The main idea of process control is to compensate the overshoot in previous according to the knowledge of system rules. The advantage of our method is that complicated works on solving the inverse matrix is not needed, and length of step, parameter of process and soften factors are all computed as simple as possible. Furthermore, in order to make it more convenient to put into practice in finance regulation, we improved the model by setting all parameters as q, λ, P, M, α adjustable. That will give the authority more flexibility to adjust the value of parameters and better fit the finance market with different attributes. By simulating the market before adjusting it, we can get a valid domain for regulation authority to operate.

4 Experimental Result and Study

Based on the operation rules of finance market, by analyzing the macro attribute of different market, we believe that tides and waves are the forms which are more likely to match the market operation trace. We chose a wave operation equation to describe the tendency, by using Matlab 6.4, the fluctuation in time period is shown. For comparison, GPC and stair-like general predication control methods. The system equation is as following

$$[1-1.474z^{-1}+0.474z^{-2}]y(k)=u(k-1)\cdot[0.445+0.163z^{-1}+0.029z^{-3}]. \tag{19}$$

Under this non-stationary noise process, the effect is shown in Figure 2 and Figure 3.

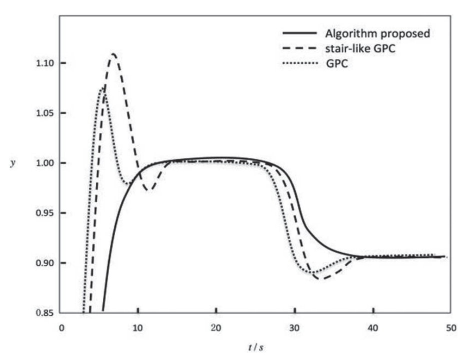

Figure 2 System output of Equation (19)

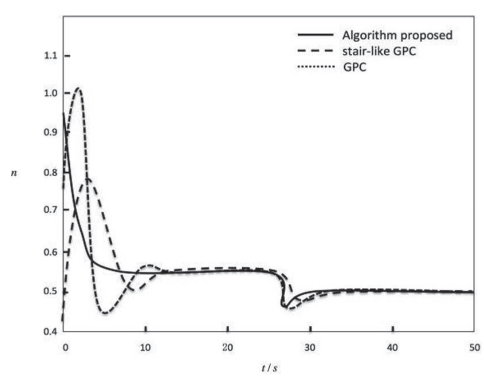

Figure 3 System input of Equation (19)

Where: $N=1$, $P=M=3$, $\lambda=0.8$, $\alpha=0$, $\beta=0.02$, $\theta=0.45$.

And if the system equation is like:

$$[1-1.2z^{-1}+0.36z^{-2}]y(k)=u(k-1)\cdot[0.1+0.2z^{-1}]. \tag{20}$$

Under this non-stationary noise process, the effect is shown in Figure 4 and Figure 5.

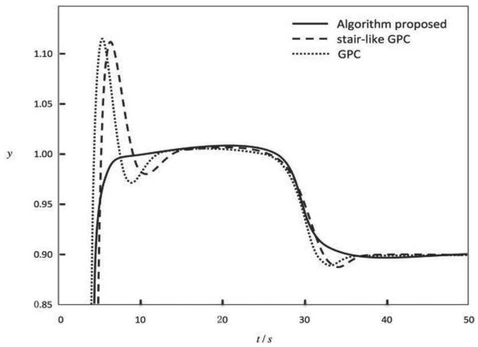

Figure 4 System output of Equation (20)

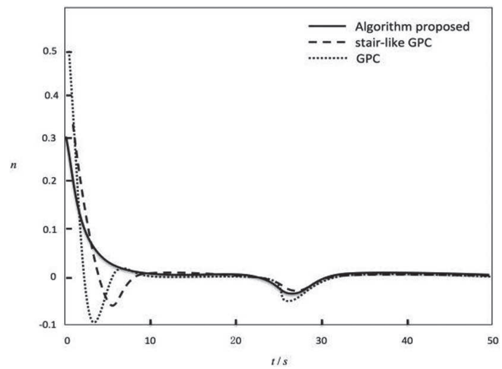

Figure 5 System input of Equation (20)

Where $N = 1$, $P = M = 3$, $\lambda = 0.8$, $\alpha = 0$, $\beta = 0.02$, $\theta = 0.5$.

The two processes we used in experiments are both partly compensated. As we set the values of θ equal to 0.45 and 0.5, respectively. Though both are only nearly half compensated, no matter to input or output, the effect are already very obvious.

After being compensated in the input, almost all the peaks and sharp points appeared in the curves became more flat, and the peak value is lower, especially in the output curves. It means we got a better solution for the system to achieve its balance with a smaller fluctuation and shorter time combination. Thus, we believe that soften factors and compensation mechanism are very effective ways to smooth the track, as long as the soften factor and compensation degree are set properly. The outer intervention mechanism will be very effective and powerful, and it can help the market to better grow and continuously come up.

This solution gives a great theoretical support to outer regulation mechanism. Macro policy and regulations from outside can dramatically improve the system operation efficiency and balance the fluctuation amplitude with the adjustment time period. By adjusting soften factor and compensation mechanism, this kind of intervention mechanism is very sensitive to those cases that the systems will overload a lot in a very short time and with a very small probability.

5 Conclusion

Overshoot related conception and algorithms under control process, provided a new approach to outer intervention mechanisms in financial market. In this paper, by compensation and soften factor adjustment, the method we prompt has the ability to build a portfolio of shorter time and lower fluctuation, which can help to control the abnormal fluctuation in finance market, manage the volatility and upgrade the stability and robustness. It can also explain counter-cyclical supervision theory and macro-prudential regulation which is very popular in banking regulation. Meanwhile, it also can give the numerical operation guide for it.

According to the observation, in finance system, overshoot value and the response time have the negative correlation, which means the longer the time period continued, the lower the overshoot value, and vice versa. In most crisis happened, the risk pattern has the character of very high overshoot together with very short time. The abnormal fluctuation bursts out suddenly. Subsequently, it demands that the finance system should have the ability to cope with it very quickly.

Authorities, the public and governments hope the market can be balanced in the way like fluctuating in a moderate amplitude and in a relatively shorter time period. While in most low efficient system, the response time from market is rather long, the time period is so long that transfers risk to many other fields and then derives other financial risks, and a shorter time period maybe better solve the problem of risk of infection. For those who has high efficiency, compared with the sharp peak, a smooth response curve will surely improve the robustness, as we have proved above. By the method we gave, systems could find a proper portfolio for time period and fluctuation. Anyway, this paper is only a fundamental exploration in this field.

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