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Impact of colored cross-correlated non-Gaussian and Gaussian noises on stochastic resonance and stochastic stability for a metapopulation system driven by a multiplicative signal☆

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ABSTRACT

In this paper, our aim is to investigate the steady state characteristics and the signal-to-noise ratio (SNR) for a stochastic metapopulation system including a multiplicative periodic signal caused by the terms of the colored cross-correlated multiplicative non-Gaussian noise and additive Gaussian noise. Numerical results indicate that the multiplicative noise, the additive one and the departure parameter from the Gaussian noise can all decrease the stability of the ecological population system and restrain the development of the metapopulation, while two noise correlation times and the strength of the noise correlation will enhance the stability of the biological system and promote the expansion of the population system. With regard to the stochastic resonance phenomenon (SR) induced by noise terms and a multiplicative weak periodic signal, the results illustrate that the noise correlation time τ and the strength of correlation noise λ can increase the SR effect greatly in most cases, while the intensity of the multiplicative noise Q mainly plays a part in suppressing the SR and weakening the SNR except that in the SNR-τ plot. Moreover, it is worth noting that the noise correlation time τ_0 and the additive noise intensity M can play the diverse roles in enhancing or weakening the SR effect under the different system parameter conditions.

1. Introduction

Stochastic resonance (SR) is a significant discovery which frequently occurs in many science fields including classical and quantum physics, chemistry, engineering, and so on. As a new conception, it was put forward firstly when scientists studied the climatic cyclical variations in ancient glacial period [1]. Afterward, an important experiment proved the mechanism of SR, which revealed the fact that the SR phenomenon exists in fact when scientists observed the signal-to-noise-ratio (SNR) in Schmitt trigger circuit and tunnel diode [2,3]. In recent decades, SR has been investigated widely in a variety of research fields and displayed important influences on them, such as information transmission, especially in biomechanics, pattern formation, overdamped monostable potential, population dynamics, the genetic toggle model, and superconducting devices [4–11]. SR phenomenon was explored in biochemical system not only in theory but also in experiments. The paddle fish judged the position of water flea via SR mechanism and SR exists in the mating behavior of Nezara viridula [12–15].

In the recent decades, the impacts of correlations between additive and multiplicative noise have been widely discussed. Many scholars have studied the steady-state and transient properties of the bistable systems with correlated Gaussian noises [16–25,35–38], and most of the previous studies have assumed that the noise is Gaussian, and on the basis of the assumption all kinds of dynamical properties for the physical and biological nonlinear systems are investigated comprehensively. However, in many practical cases, external distributions are not Gaussian. Many experimental evidences, particularly in sensory and biological systems [26], indicate that the study of non-Gaussian noises is indispensable [27–31]. The stochastic resonance induced by non-Gaussian colored noise has been examined [32–34]. The effective Markovian Fokker–Planck equation for the stochastic system driven by non-Gaussian noise has been obtained by using a path integral approach [27].

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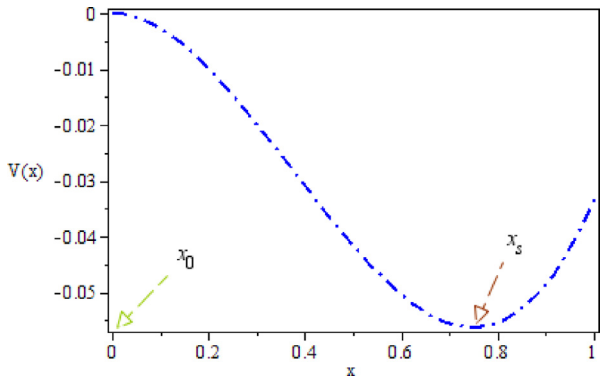

Fig. 1. The monostable potential $V(x)$. The parameters take $c = 0.8, e = 0.2$. The stable states is$x_s = 1 - e/c$, and one unstable state is $x_0 = 0$.

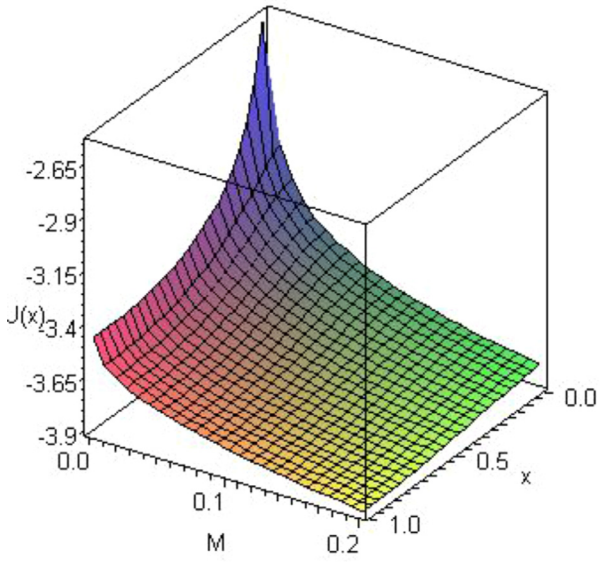

Fig. 2. Three-dimensional curves of the effective potential $U(x)$ versus x and M when other parameters take $Q = 0.2, \lambda = -0.5, \tau_0 = 0.3, \tau = 0.3, q = 0.5, A = 0.0, c = 0.8, e = 0.2$.

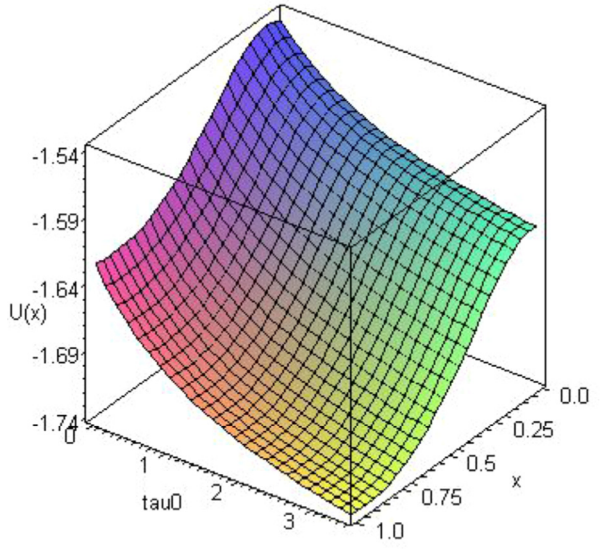

Fig. 3. Three-dimensional curves of the effective potential $U(x)$ versus x and τ_0 when other parameters take $Q = 0.2, \lambda = -0.5, M = 0.01, \tau = 0.3, q = 0.5, A = 0.0, c = 0.8, e = 0.2$.

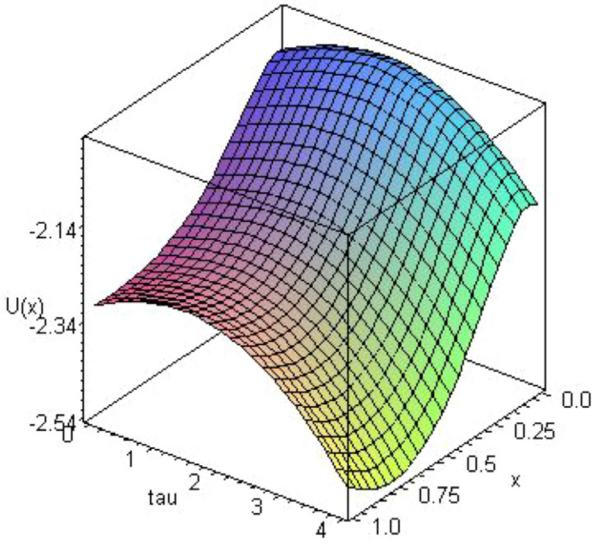

Fig. 4. Three-dimensional curves of the effective potential $U(x)$ versus x and τ when other parameters take $Q = 0.2, \lambda = -0.5, M = 0.01, \tau_0 = 0.3, q = 0.5, A = 0.0, c = 0.8, e = 0.2$.

The fact that the stationary probability density and the mean first-passage time can be influenced by correlation intensity and correlation time has been shown for the stochastic system with coupling between non-Gaussian and Gaussian white noise [28].

The model of metapopulation is firstly established by Levins during the process of studying the extinction phenomenon of species due to the influence of the environment. On the basis of the Levins' model, many ecologists made a great deal of research on the dynamics of metapopulation systems. [39–45] Until now, Levins' model has been thought of as the mother of the metapopulation system. Whereas, in practice, most of the obtained works are limited to the deterministic Levins' model, for which, both the influence of the external environment and the undulation effect within the metapopulation system are ignored. Nowadays, a fact verified by many researches is that under the practical condition, noises have a significant influence on the dynamical behaviors for nonlinear biological systems.

In this paper, we aim to investigate the steady-state behaviors and the SR phenomenon of a metapopulation system which is subjected to the colored correlated multiplicative non-Gaussian noise and additive Gaussian noise together with a multiplicative periodic signal. In Section 2, we give the stochastic metapopulation model subjected to the colored cross-correlated Gaussian white noise and non-Gaussian noise. In Section 3, the influence of the non-Gaussian noise, the Gaussian noise and the noise correlation as well as their correlation times on the steady-state probability distribution function and the effective potential function of the metapopulation system are discussed in detail. In Section 4, some interesting SR phenomena of the SNR in the metapopulation system induced by the colored correlated Gaussian and non-Gaussian noises are analyzed systematically. In the final section, a detailed conclusion is drawn ultimately.

2. Stochastic metapopulation model induced by colored cross-correlated Gaussian and non-Gaussian noises

Levins [39,40] raised firstly a question on the metapopulation model when he was investigating the extinction process of species due to the fluctuation of the outside world. To this day, the metapopulation theory has been thought of as a strong tool to an-