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International Stability under Iterated Sanctions and Counter-sanctions

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Abstract: In this paper, some discrete mathematical models for dynamics of two antagonistic parties (opponents) under iterated sanctions and counter-sanctions are proposed. The modeling approach is inspired by the Osipov-Lanchester bilinear model for warfare. The criteria for model stability are derived both for the full information case and for the stochastic and nonlinear uncertainty case. The controlled version of the model described by bilinear difference equations is proposed, and a statement concerning controllability of the model by small controlling actions is formulated. The results are interpreted in terms of international stability preservation. The risks of global instability caused by further increase of sanctions intensity are formulated. A possible way of international stabilization control by small actions based on mutual trust of parties is proposed and discussed.

1. INTRODUCTION

The exchange of sanctions and counter-sanctions is a fairly common form of international relations in conflict situations. However, over the past decade, the frequency and the intensity of imposed sanctions have increased significantly. In some cases, this even led to a deterioration in the economic situation in countries. Sanctions are making a significant impact on the world economy and international stability. Further increase of sanction activity may increase the risk of global war. Therefore, there is a need for research of international dynamics and stability in the face of multiple sanctions and counter-sanctions.

There is a significant amount of research on international stability and sustainability Dimirovski et al. (2006); Erbe and Kopacek (2008). An important activity is going on within the IFAC TC 9.5 offering new approaches to the study and discussions of international stability and sustainability Stapleton and Kopacek (2011); Stapleton and Stapleton (2017). In Ojleska et al. (2009) the problem of cooperation, non-cooperation and conflicts has been investigated using Fuzzy Matrix Game Theories. The control system approaches were used by Dimirovski et al. (2006) for study of sustainable development and global instability management.

There are significant number of works devoted to the study of the world economy under sanctions. They use the methods based on game theory Tsebelis (1990); Ogawa and Yanase (2019) fuzzy cognitive maps Groumpos (2019) and so on. However, there are just a few works studying influence of sanctions on international stability and global processes. Apparently this is due to the fact that until the last decade, sanctions and counter-sanctions were relatively local were not multiple and repeated and did not require dynamic models to be studied.

Methods of mathematical modeling and automatic control can shed light on some of the mechanisms and patterns of these processes. Mathematical models of such situations are not currently available, up to the author's best knowledge. Therefore, it seems important to take the first steps in this direction, to propose the simplest mathematical models of the situation and try to outline ways to study international stability and instability based on these models. This is just what this article is devoted to. Some preliminary results presented in the paper are published in Fradkov (2022).

The role of sanctions is similar to the role of military operations in that they are aimed at the weakening of the opposite party of the conflict. However, mathematical models of sanctions differ from the models of military operations and have been little studied before. The peculiarity of the current period of international relations is in that the sanctions are applied by different parties iteratively, in packages and stages. They have a dramatic effect on international relations. However, there are still no simple mathematical models describing the main effect of sanctions and allowing one to derive stability conditions.

Below, we propose a simple model of repeated sanctions and counter-sanctions mutual dynamics, motivated by and having similarities with the Osipov-Lanchester model. Stability conditions for the overall system are derived both for deterministic case and in presence of stochastic or nonlinear uncertainty.

2. MODELS OF MILITARY OPERATIONS

In this section we recall for completeness, following Helmbold (1993); Washburn and Kress (2009) the simplest Osipov-Lanchester model described by a system of two linear differential equations

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$$\dot{R}(t) = -\alpha G, \dot{G} = -\beta R, \tag{1}$$

where R, G are numbers of the units representing power of each opponent, α, β are firing intensities (efficiencies). Using Euler method a discrete time version of (1) can be written as follows

$$\begin{cases} R_{n+1} = R_n - \alpha \Delta t G_n, \\ G_{n+1} = G_n - \beta \Delta t R_n, \end{cases} \tag{2}$$

where Δt is sampling interval. The system (2) can be considered as a model for warfare in its own right, with each iteration corresponding to a separate battle.

Since model (1) is usually called the "Lanchester model", it is necessary to explain why the term "Osipov-Lanchester model" is used in the article. The fact is that model (1), the author of which is usually considered to be Frederick Lanchester, who presented it in the book Lanchester (1916), published in 1916, actually appeared for the first time in an article by Mikhail Osipov Osipov (1915), published in Russia in 1915. This is substantiated in Helmbold's article Helmbold (1993). The article Helmbold (1993) analyzes the relationship between the works of Lanchester and Osipov in detail. It is shown that their results were obtained independently. A similar conclusion was made in an article Yusupov and Ivanov (1988) published in the USSR in 1988. Therefore, it would be historically correct to call model (1) the "Osipov-Lanchester model".

Interestingly enough, little is known about the first author of the model (1), M.P. Osipov, and little has been written, even in Russia. Not a single paper refers to Yusupov and Ivanov (1988) except Helmbold (1993). The credit for identifying the author of these articles, M. Osipov, with General (retired) M. P. Osipov also belongs not to Russian historians, but to an American scientist J. W. Kipp, at that time (2004) director of the US Foreign Military Research Administration. He published his work in the "Journal of Slavic Military Research" Kipp (2004). More detailed information about the life of M.P. Osipov can be found in the article by N.V. Mityukov Mitjukov (2011), We discuss it here, following Mitjukov (2011), since this information was not published in English before.

Mikhail Pavlovich Osipov was born on October 1, 1859. His parents chose a military career for him: he was brought up at the Vladimir-Kyiv military gymnasium, after which he graduated from the Second Konstantinovsky Military School. He served in different regions of Russia and in 1912 rose to the rank of general. On duty, Mikhail Pavlovich was engaged in geodetic and astronomical research, actively using the mathematical apparatus. In 1901-1903 he was engaged in astronomical observations in the Yenisei province and the Semipalatinsk region, specifying the geographical coordinates of a number of locations. Probably, he achieved the greatest success as a geophysicist in 1902, having determined, together with Major General Yu. A. Schmidt, the difference between the longitudes of towns Minusinsk and Achinsk. Many of the results of his research have been published in specialized literature. But in 1910, on the basis of many years of work, he also published a purely mathematical work - "The influence of refraction on geometric leveling."Osipov (1910) For family reasons, General M.P. Osipov retired in March 1913.

Fig. 1. Mikhail Pavlovich Osipov (courtesy of the Bulletin of geodesy, cartography and geoinformatics)

Being unable to participate in the combat battles of the World War I, he thought about how to gain an advantage in war with the help of mathematics. He analyzed 38 battles of the past using data from the open press (military reference books, encyclopedias), illustrating his reasoning with a number of tables and examples, which he formulated in the style of a standard mathematical problem book.

There is no information about the further life of Osipov. Among the former tsarist officers who entered the service in the Red Army, M.P. Osipov is not listed. There is none and among the repressed and killed during the Civil War. As a result, his date of death remains unknown. Photo of M.P. Osipov borrowed from the site Vishnyakov (2021) is seen in Fig.1.

It is curious that Rafael Yusupov, the author of the first article in Russian, where the contribution of M. Osipov was presented, was also a military man and retired as a major general. He is also an expert in the theory of automatic control. His monograph on sensitivity theory, joint with E.N. Rosenwasser, published in Russian in 1973, was translated into English 27 years later, in 2000 Rosenwasser and Yusupov (2000).

3. MODELS OF SANCTIONS AND COUNTER-SANCTIONS DYNAMICS

The Osipov-Lanchester equations are not suitable for description of economical or political sanctions, since efficiency of a sanction package is mainly determined by its negative influence on the opponent with respect to the opponent's counter-sanction package at the previous stage. Given a diplomatic tradition of "mirror response", the sanction intensity at the next stage should be almost similar or at least not weaker than the intensity of counter-sanction at the previous stage. Note that the meaning of the term "not weaker" might depend on the public opinion even stronger than on the real economic effect. This claim is illustrated by the whole international sanction history of the last decade. Moreover, the sanctions and counter-sanctions of 2022 often lead to negative economical effect for countries imposing sanctions.

In order to jump to the equations, let us consider small historical periods and make an assumption that the long term adaptation of the countries under economical sanctions (like in the case of Iran, see Popova and Rasoulinezhad (2016)) is negligible. Under such assumptions, the strength (weakness) of the sanction depends mostly on the increase (decrease) of the sanction pressure (increment) during the previous sampling interval (stage). At the first step assume that all dependencies are linear and deterministic. Then we arrive at the following equations:

$$\begin{cases} x_{n+1} = x_n + \alpha(y_n - y_{n-1}), \\ y_{n+1} = y_n + \beta(x_n - x_{n-1}), \\ n = 1, 2, ... \end{cases} \tag{3}$$

where x_n, y_n are values of sanction and counter-sanction pressure at n^{th} sampling instant, α, β are positive cross-gain parameters. Equations (3) thus represent a linear model of sanction dynamics. Cross-gains α, β in general differ from the corresponding coefficients in (1),(2) In addition to direct economical impact (such as e.g. export earnings) they depend also on national mentality, activity of independent media and life standards in the countries involved. The question: how to choose α, β will be discussed later.

In order to transform (3) into a more convenient form denote $v_n = x_n - x_{n-1}, w_n = y_n - y_{n-1}$. Then (3) takes form of vector power series

$$\begin{cases} v_{n+1} = \alpha w_n, \\ w_{n+1} = \beta v_n, \\ n = 1, 2, ..., \end{cases} \tag{4}$$

Shift n to $n-1$ in the second equation of (4) and substitute it into the first one. Then perform similar procedure with the first equation of (4). We come up with the following equations:

$$\begin{cases} v_{n+1} = q v_{n-1}, \\ w_{n+1} = q w_{n-1}, \\ n = 2, 3, ... \end{cases} \tag{5}$$

where $q = \alpha\beta > 0$ is the total gain of the system.

Analysis of the linear system (5) yields first conclusions concerning asymptotic behavior of the process. The only parameter influencing stability of (5) is the total gain q. The system is asymptotically stable, i.e. $v_n \to 0, w_n \to 0$ as $n \to \infty$ for any initial conditions v_0, w_0 if and only if $q < 1$. If $q > 1$ then the solutions tend to infinity for all nonzero initial conditions. The boundary case $q = 1$ corresponding to Lyapunov stability has zero measure in the space of the parameters α, β and can be neglected.

An important observation is that strategy parameters α, β of the opponents enter expression for q symmetrically. It means that both sides are equally responsible for keeping the stability of the process. Second important observation is that each opponent is able to ensure stability of the process by means of proper choice of its strategy (decreasing its own gain α or β). In other words it is profitable for each party to decrease q since increase of q leads to instability which is disadvantageous both for that party and for the whole system.

Note that the solutions to (4) may be represented explicitly as power functions of time

$$\begin{cases} x_{2n} = (q^n - 1)/(q-1)(y_1 - y_0)/\beta, \\ x_{2n+1} = (q^n - 1)/(q-1)(x_1 - x_0)/\beta, \\ n = 1, 2, ... \end{cases} \tag{6}$$

Relations (6) and similar expressions for y_n represent long term cumulative effect of sanctions. It seems however that sanctions of the past weakly influence economic wealth and public opinion in long term since each opponent takes all measures to suppress the effect of the sanctions as soon as possible.

4. STOCHASTIC MODEL OF THE REPEATED SANCTIONS DYNAMICS

Idealized model (3) has an apparent drawback that it may be supersensitive to the parameter values α and β. In reality the values of α and β depend in a complex way on many factors, including economical, political ones and on public opinion. Moreover the values of α and β may change from stage to stage. The simplest model for uncertainty is randomness. Therefore a model with random parameters is proposed and analyzed in this section.

Suppose that α and β in (3) are replaced with $\alpha + \xi_n$ and $\beta + \eta_n$, respectively. The stochastic version of (3) is as follows:

$$\begin{cases} v_{n+1} = (\alpha + \xi_n) w_n, \\ w_{n+1} = (\beta + \eta_n) v_n, \\ n = 1, 2, ..., \end{cases} \tag{7}$$

The random fluctuations are assumed to have zero means and bounded variances:

$$E\xi_n = E\eta_n = 0,$$
$$E\xi_n^2 = \sigma_x^2, E\eta_n^2 = \sigma_y^2,$$
$$n = 1, 2, ...$$

where E stands for mathematical expectation. Assume additionally that the fluctuations for different opponents are uncorrelated: $E\xi_n\eta_m = 0$ for all $m, n = 0, 1, 2, ...$ and analyze mean square stability of (7).

Under imposed assumptions the mean squares of the variables in (7) satisfy the relations $Ev_{n+1}^2 = E[(\alpha + \xi_n)(\beta + \eta_n)]^2 Ev_{n-1}^2$. It means that the stability of the system depends on the averaged gain $\bar{q} = E[(\alpha + \xi_n)(\beta + \eta_n)]^2$. Evaluation of the averaged gain yields:

$$\bar{q} = E(\alpha^2 + 2\alpha\xi_n + \xi_n^2)(\beta^2 + 2\beta\xi_n + \xi_n^2)$$

Taking into account the zero correlation assumption we obtain

$$\bar{q} = (\alpha^2 + \sigma_x^2)(\beta^2 + \sigma_y^2). \tag{8}$$

It is seen that the same conclusions hold for stochastic case if the gain q is replaced with the averaged gain $\bar{q}$. It is seen also that stability conditions for stochastic case are more strict since $\bar{q} > q$. Note that stability may be achieved in principle only under condition $(\sigma_x^2 + \sigma_y^2) < 1$.

5. CONTROLLED MODEL AND STABILITY CONTROL

Suppose that the control of the situation is possible by the change of the coefficients α and β. Although true values of α and β are unknown, each party obviously has an ability to change their values due to the strengthening and weakening of influence of the measured effect of sanctions at the next stage. Introducing controlled factors u_n, z_n rewrite the model equation (4) in the following form.

$$\begin{cases} v_{n+1} = \alpha_n w_n, \\ w_{n+1} = \beta_n v_n, \\ n = 1, 2, ... \end{cases} \tag{9}$$

where $\alpha_n = \alpha u_n, \beta_n = \beta z_n$, and u_n, z_n are controlling factors, $0 < u_n < 1, 0 < z_n < 1$. Since the control goal is achievement of the stability, we do not consider the value of controlling factors greater than 1. Thus the controlled model is described by bilinear difference equations (9). Note that the model total gain $q_n = \alpha\beta u_n z_n$ depends symmetrically on the value of the control variables of both parties.

The bilinear nature of the model suggests the mechanism of control aimed at providing stability. In order to decrease the total gain q_n each party should choose control variables strictly less than one. The following result may be easily proven.

Proposition 1. For any initial conditions v_1, w_1, any parameter values α, β and any value of the threshold $0 < \varepsilon < 1$ the choice of control factors satisfying $0 < u_n < 1-\varepsilon, 0 < z_n < 1-\varepsilon$ ensures stability condition $q_n \le q < 1$ for all $n > n_*$ after some number of steps n_*.

The above result provides a control rule which is extremely simple: each party at each stage should change its controlling variable in such way that the total gain q_k strictly decreases. It is amazing that in order to achieve stability an arbitrarily small decrease of u_n, z_n is sufficient independently of the value of unknown parameters. Such a control looks like just a demonstration of good will: let your opponent know that you reduce sanctions if the opponent will do the same. Apparently we have shown mathematically that such a procedure ensures international stability. A good example illustrating this rule is the history of the recent "grain deal", see UN-news (2022) and further publications.

6. EXTENSION TO NONLINEAR MODELS

It may seem that the simplicity and clarity of the conclusions from the constructed mathematical model of the dynamics of the sanctions and counter-sanctions are a consequence of the simplicity of the chosen model, in particular, its linearity. Therefore, it is of interest to investigate whether the obtained conclusions change if nonlinearities are introduced into the linear right hand sides of model (3). The first thing that comes to mind is to replace the proportional ratios with arbitrary continuous functions, as was proposed by V.I. Arnold Arnold (1998), thereby moving from "hard" to "soft" mathematical models. Arnold applied this approach to the Osipov-Lanchester battle model. However, it is desirable to retain the ability to draw not only qualitative but also quantitative conclusions from models. Therefore, we will replace linear dependencies with nonlinearities not with an arbitrary slope, but with functions whose graphs lie in some sectors in the plane. This formulation of the problem is inspired by the Lurie problem in the theory of absolute stability Liberzon (2006).

Suppose that instead of (3), the model of the processes under study is described by nonlinear relations

$$\begin{cases} x_{n+1} - x_n = \alpha_1(y_n - y_{n-1}) + f_1(y_n - y_{n-1}) \\ y_{n+1} - y_n = \alpha_2(x_n - x_{n-1}) + f_2(x_n - x_{n-1}) \\ k = 1, 2, ... \end{cases} \tag{10}$$

It is assumed that the nonlinearities $f_1(x)$ and $f_2(y)$ are continuous, but not known exactly. The only thing known about them is that they satisfy the relations

$$0 \le \frac{f_1(y)}{y} \le \mu_1, 0 \le \frac{f_2(x)}{x} \le \mu_2, \tag{11}$$

which mean that their plots lie in some sectors in the plane.

Consider the following stability problem: for what values of parameters $\alpha_1, \alpha_2, \mu_1, \mu_2$ system (10),(11) is stable in the sense that the solutions x_n, y_n are bounded and their increments $v_n = x_n - x_{n-1}, w_n = y_n - y_{n-1}$ tend to zero for any initial conditions x_0, y_0:

$$\lim_{n\to\infty} v_n = 0, \quad \lim_{n\to\infty} w_n = 0. \tag{12}$$

The stated problem belongs to the class of problems of absolute stability: we are interested in the stability of discrete nonlinear system (10) for any nonlinearities from the given class (11). For continuous systems, such a problem was first posed in 1944 Lurie and Postnikov (1944). In our case the problem is easy to solve since it is related to two-dimensional dynamical systems. Moreover it can be reduced to the one for one-dimensional systems in a way similar to the linear case. The result is formulated in the following statement.

Proposition 2. For stability of the system (10),(11) in sense (12) the fulfillment of the relation

$$\bar{q} < 1, \tag{13}$$

where $\bar{q} = (\alpha_1 + \mu_1)(\alpha_2 + \mu_2)$ is necessary and sufficient.

Proof. *Sufficiency.* Make the shift $n \to n-1$ in the second equation (10) and substitute it into the first equation. We obtain the equation

$$v_{n+1} = \alpha_1\alpha_2 v_{n-1} + \Psi(v_{n-1}), \tag{14}$$

where $\Psi(v) = \alpha_1 f_2(v) + f_1(\alpha_2 v + f_2(v))$. In view of (11) the following inequalities hold:

$$0 \le \Psi(v) \le \alpha_1\mu_2 v + \mu_1(\alpha_2 + \mu_2 v)$$

Hence $v_{n+1} \le \bar{q}v_{n-1}$ and for any $v(0)$ the sequence v_n tends to zero exponentially for even n. Similarly, v_n for odd n tends to zero exponentially for any $v(1)$. Let $v_n < 0$ for some $n = n^* > 0$. Then the choice $\Psi(v) = 0$ yields $|v_{n^*+2}| = -\alpha_1\alpha_2|v_{n^*}|$ and therefore v_n tends to zero exponentially since $0 \le \alpha_1\alpha_2 < 1$. Therefore $x_n = x_1 + \sum_{k=1}^{n} v(k)$ is bounded and tends to some constant.

Necessity. Let $\bar{q} \ge 1$. Choose nonlinearities as $f_i(v) = mu_i v, i = 1, 2$. Then $v_n = \bar{q}^n v(0)$ does not tend to zero as $n \to \infty$ for nonzero v_0.

An analysis of relation (13) shows that it is invariant under the permutation of indices: the replacement of index 1 by index 2 and vice versa. Therefore relation (13) is invariant under the permutation of the parties in the conflict. Thus, we can conclude that both opponents (both sides of the conflict) in the non-linear case bear equal responsibility for sustainability and fragility of conflict development as in the linear case.

7. CONCLUSIONS

The paper provides only a conceptual exposition of the proposed model and its properties. Such important issues as evaluation of the model parameters and using the model in practice as well as taking into account nonlinear effects are beyond this discussion.

The first important conclusion is that both opponents are equally responsible for stability of the process. If one of the opponents increases strength of its sanctions unlimitedly without coordination with the other opponent then instability occurs for sure (in stochastic case in mean square and with probability one). It means that international stability may be achieved only by coordinated efforts of all countries (parties). Coordination should take into account that the values of the parameters α, β are different since they depend on historical, cultural, geopolitical aspects.

The second conclusion is that in the deterministic case each opponent is able to ensure stability of the process by means of proper choice of its own strategy (decreasing its own gain). However, in the stochastic and nonlinear cases it is not always possible. Stability may be achieved only under condition $(\sigma_x^2 + \sigma_y^2) < 1$ in the stochastic case and under condition $(\mu_1 + \mu_2) < 1$ in the nonlinear case. Therefore, uncertainty matters. Nevertheless, it is still profitable for each opponent to decrease q since increase of q leads to instability which is disadvantageous both for that opponent and for the whole system.

An interesting side result is the extension of linear models to the nonlinear case in spirit of Arnold's "soft models" Arnold (1998). Unlike the original Arnold's scheme, our approach is based on the so called Lurie model of sector bounded nonlinearities. It opens a way to using "restricted soft models" or "semisoft models" allowing for quantitative conclusions in addition to the qualitative ones. For more complex models the frequency domain stability criteria for discrete time systems Yakubovich (1968) can be employed.

At the moment, it seems most important to broadly disseminate the results of this paper among professional community, public media and governments to make them aware of the risks of global instability caused by further increase of sanctions intensity and possible way of control of situation by small actions based on mutual trust of parties.

The cost of the instability and global war exceeds any economical losses we can imagine.

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