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Simulations of Public Debt

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Abstract: Public debt trajectories are multidimensionally interconnected with the other processes in the economy, and as such, they had better be analyzed within a system framework that takes into account the public-debt related interrelations and feedback loops which could involve many macroeconomic as well as microeconomic factors (including the non-economic ones) that could have significant influences on the trajectories in question. In this paper, we develop a simple system-based framework where we begin to exemplify the interrelations and causal connections embodied within the system. By explicating such interrelations, we will account for the underlying interconnectivity that, together with other factors, give rise to the formation of the debt trajectories which could span over a number of years. Once the underlying interconnectivity and the relevant factors are specified, we can construct a system dynamics model so as to simulate the debt trajectories under conditions that are of practical significance to policy makers. Simulating the trajectories, with a reasonable degree of accuracy, opens the doors to the optimal management of debt processes. Correctly predicting the debt figures at different points in time enables the policy makers to design and implement policies so as to influence/control the trajectory to achieve the debt-related objectives. An example of the policy of this kind will be provided in the text.

Keywords: Public debt, Simulation, System dynamics, Policies.

Introduction

Debt dynamics is a complex process with multiple dimensions, the interconnections and interactions of which could produce a wide spectrum of issues and problems that are worthy of in-depth examinations. The literature on debt contains various works exploring a subset of these issues and problems. Some of these works are related to the internal dynamics of debt in one way or the other. Among these are Katsikas et al. (2023), which examines the dynamic stability of public debt and its solvency condition at a specific crisis juncture, Bocola and Dovis (2019), which explores the self-fulfilling nature of debt crisis in a quantitative framework, D'Erasmo et al. (2016), which deals with the issue of the sustainability of public debt and Li et al. (2022), which studies the sovereign debt dynamics in cases where the government have present-biased preferences. Some works, on the other hand, tackle with specific economic problems in connection to debt. Works in this category include Gómez-Puig and Sosvilla-Rivero (2018), Checherita-Westphal and Rother (2012), which analyze the issue of public debt and economic growth, Akitoby (2017), which investigates inflation and public debt reversals in the G7 countries, Okamoto (2024), which studies welfare and demographic dynamics in relation to optimum quantity of debt, Banaszewska (2023), which looks into the issue of spatial interactions in local debt, Alberola et al. (2023), which delves into the matter of unconventional monetary policy and debts unsustainability, and Konishi (2018), which undertakes a dynamic analysis of budget policy rules and Irwin (2015), which deals with the definitions of debt and deficit. There are also works that focus on selected debt-related topics of specific complexities, such as Carvelli (2024), which examines exogenous variations in public debt and the private output, De Soyres et al. (2022), which revisits the issue of public debt and real GDP and Furceri et al. (2022), which analyzes the distributional effects of government spending shocks in developing economies.

In view of the multidimensionality of the debt-related problems, it may prove to be productive to choose a system framework that enables the dynamic analysis of the interactions of multiple dimensions and the feedback loops associated with those interactions. In the literature, there are works, such as Steerman (2000), Kara (2023a, 2018b, 2015c), exemplifying, in different contexts, a system dynamics perspective that can be effectively used for the purpose of modeling debt dynamics. In this paper, we will use such a perspective to derive the trajectories of debt, deficit and national income and undertake some policy exercises. The second section develops a model of debt dynamics in a simplified framework. The third section presents simulation results for exemplification purposes. Concluding remarks are indicated in the last section.

Method

Consider a macroeconomic system where C_t, I_t, G_t, X_t-M_t, respectively, represent the consumption, gross investment, government spending and net export components of the aggregate demand (AD_t) at time t. Y_t, Yd_t, r_t, and t are the national income, disposable income, interest rate and net tax rate, respectively. For the sake of simplicity, suppose that depreciation = 0, indirect taxes = 0 and net factor income from abroad = 0. C_t is assumed to be a linear function of Yd_t and r_t and a normally distributed stochastic factor u_t while I_t linearly depends on r_t but nonlinearly depends on the first-differenced national income differentials as well as a normally distributed stochastic factor v_t. G_t is assumed to grow at a constant rate and includes the “interest rate on debt” as an additional component. X_t is taken to be exogeneous and M_t depends on national income, rendering the net exports a linear function of national income with exports as a constant component. Thus,

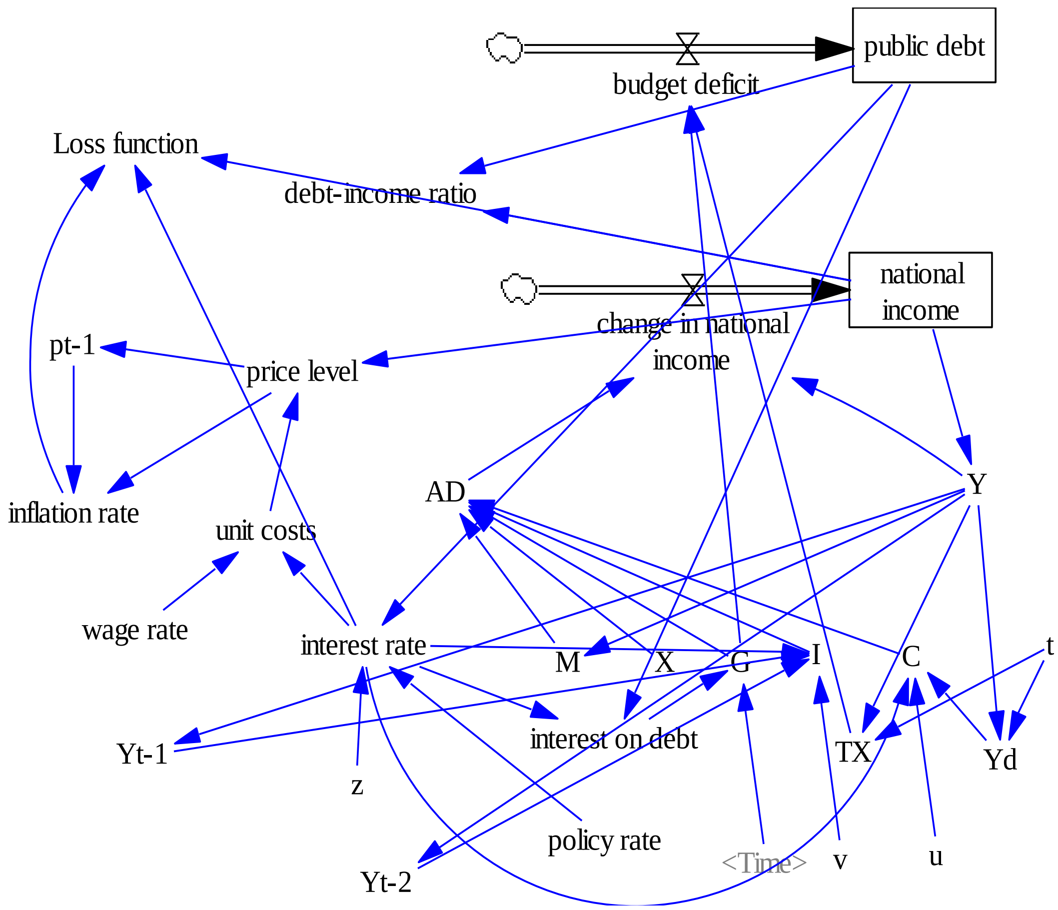

Figure 1. The simulation diagram

$C_t = a_0+a_1.Yd_t+a_2.r_t +u_t$ (1)

$I_t = b_0-b_1.r_t+b_2.(Y_{t-1}-Y_{t-2})+b_3.(Y_{t-1}-Y_{t-2})^\wedge 2+b_4.(Y_{t-1}-Y_{t-2})^\wedge 3+v_t$ (2)

(For an example of a nonlinear investment function in cubic form, see María Muñoz-Guillermo (2021))

$G_t = c_0.(1+c_1)^\wedge t$ + interest on debt (3)

$X_t-M_t = d_0 + m.Y_t$ (4)

The analysis of interest rates in particular and costs in general would require the analysis of input markets as well, which we will not delve into in this paper. Instead, we will make the following simplifications.

$r_t = e_1$.(the central bank's) policy rate+e_2.public debt + z_t, (5)
unit cost = f_1.interest rate+f_2.wage rate, (6)
where z_t is a normally distributed stochastic term.
On the other hand, the analysis of price levels would require an analysis of supply side dynamics, which will not be taken up here. For p_t, we will make the following simplification.
$p_t = g_1$.unit cost+$g_2.Y_t$. (7)

There are some other variables that will be defined in the relevant contexts below. To model the relationships among the variables within the system, we will use the method of system dynamics which, in general, requires the specification of stock variables, flow variables, auxiliary variables and the feedback relations in the system. Stock variables represent the accumulated values of some key variables. A flow variable represents the change in the relevant stock variable. The other variables in the system are called auxiliary variables that influence, in one way or the other, the values of the stock or flow variables within a web or relationships that may involve some feedback loops representing the chain of causal connections within the system. We will represent the system of these relationships with a system dynamics simulation diagram, which is as follows:

Results and Discussion

We will use the following parameter values for the simulation of the basic variables:

a_0 = 125, a_1 = 0.8, a_2 = -500, b_0 =250, b_1= 250, b_2 = 0.001, b_3 = 0.0001, b_4 = 0.00001, c_0 = 225, c_1 = 0.015, d_0 =100, m = 0.1, e_1 =0.5, e_2 = 0.005, f_1 = 0.5, f_2 = 0.5, g_1 = 0.5, g_2 = 0.001.
u = RANDOM NORMAL (-80, 100, 10, 10, 0)
v = RANDOM NORMAL (-60, 80, 10, 10, 0)
z = RANDOM NORMAL (-0.01, 0.05, 0.02, 0.02, 0)

The obtained trajectories, with these parameter values, of the public debt, national income and debt-income ratio are given in Figure 2, Figure 3 and Figure 4. The trajectories reflect the effects of factors such as interdependencies, nonlinearities and "stochasticities". There are feedback relations within the system that influence the shape of the trajectories as well. For the sake of illustration, we will point out two of them. First, the public debt influences the interest rate, which influences the interest rate on debt, which influences the government spending, which influences the budget deficit and hence the public debt, completing the feedback loop. Second, the national income influences, the disposable income, the consumption, the investment and the imports, which influence the aggregate demand, which influences the change in the national income, which influences the national income, completing the feedback loop.

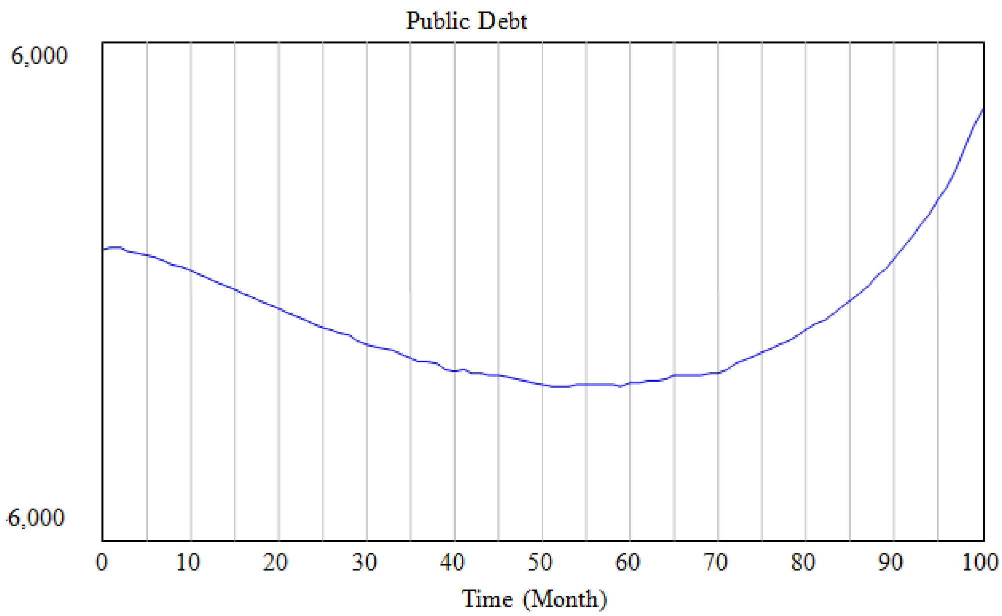

Figure 2. The public debt trajectory

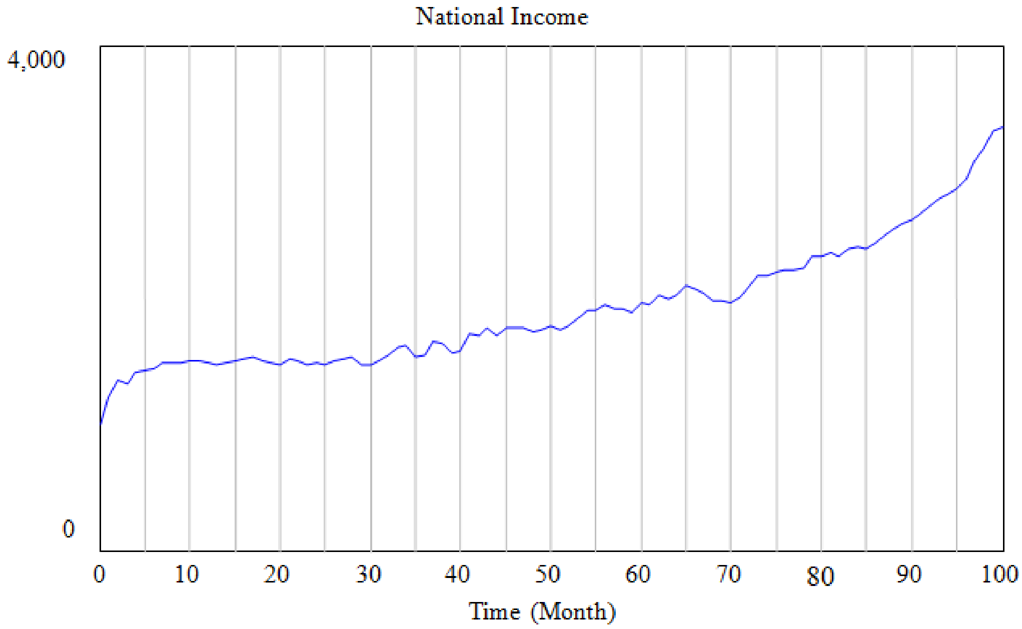

Figure 3. The national income trajectory

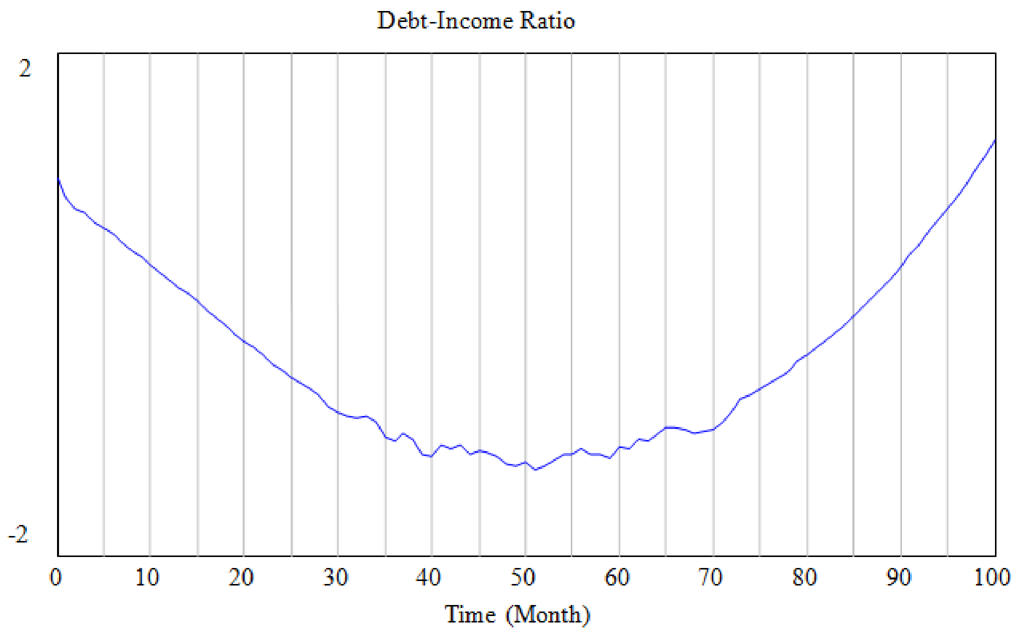

Figure 4. The debt-income trajectory

Within this system, which can be extended to incorporate many different complexities, we can begin to undertake policy exercises of practical significance. We will exemplify simplified versions of two possible policies. First, we can simply simulate the effects of a change in the basic parameter of government spending growth, $c_{1.}$ Suppose that the value of the parameter in question is decreased from 1.5 % to 1.4 %. The effect on the public debt over the selected simulation period is shown in Figure 5. .

As the trajectory in Figure 5 shows, the public debt would be significantly reduced over the period in question compared to the debt displayed in Figure 2. The second policy exercise we will exemplify will involve the determination of optimal value of a policy parameter that will maximize a chosen objective function. Suppose that the policy makers try to minimize a loss function which consists of two components, namely, the squared deviation of national income from a targeted national income and the squared deviation of inflation rate from a targeted inflation rate. Suppose that the policy maker intends to find the value of the net tax rate that minimize this loss function. For illustration, we assumed that the targeted national income is 2500 and the targeted inflation rate is 4%. We have undertaken this optimization with VENSIM DSS and within the simulation setup above and obtained the optimal net tax rate of 0.251258. Similar policy optimization exercises could be undertaken with specifically chosen welfare functions to be maximized.

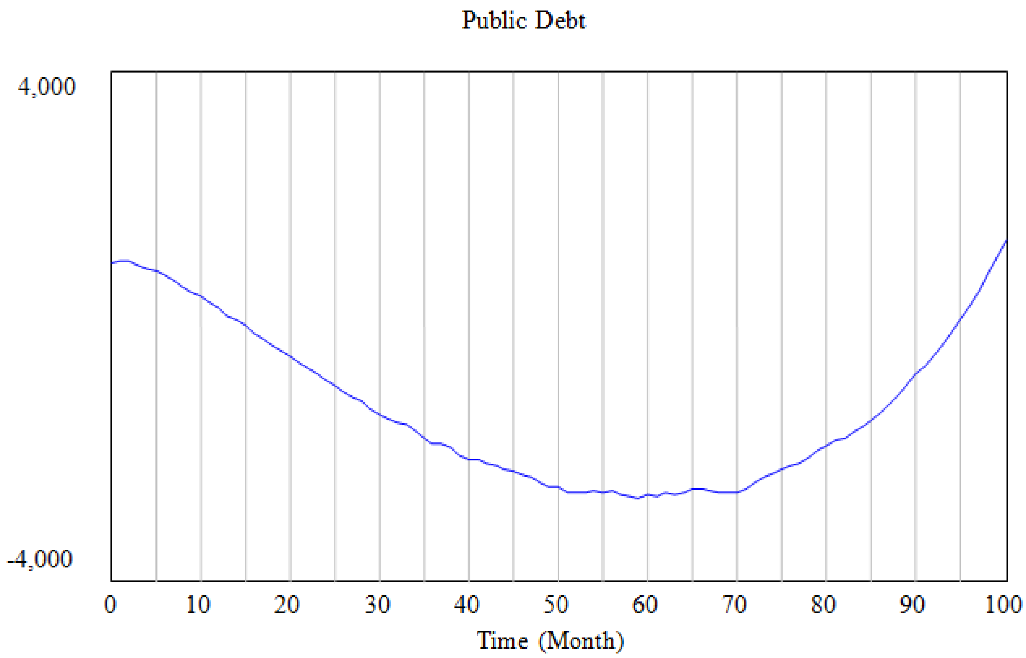

Figure 5. Public debt with 1.4 percent growth in the government spending

Concluding Remarks

In this paper, we have demonstrated a way in which one can begin to undertake a system-based modeling of public debt. The setup we have proposed can be extended and generalized so as to take into account many different complexities that can arise in debt-related processes. The simple setup we begin with includes public debt and national income as "the stock variables", the changes of which are "the flow variables". The other variables are of auxiliary type facilitating the causal specification of the variables within the system. The chain of causal connections forming feedback loops within the system play a key role in a detailed account of the dynamic of the system. The number of the stock, flow and auxiliary variables could be increased as the need arises. Using this system, we have exemplified and simulated a particular policy that can reduce, in a quantifiable manner, the public debt over time. With a sufficiently realistic (empirically-based) setup, quantification could turn out to be realistic as well. Similarly, one can design and simulate many different policies or combinations of policies that would enable the policy makers to achieve the chosen policy targets. Moreover, the policy makers could also try to determine the optimal values of certain policy parameters, such as taxes or policy- interest rates, so as to maximize overall social welfare functions.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPESS Journal belongs to the authors.

Acknowledgements or Notes

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