RESEARCH PAPER

Nonlinearity, Endogeneity, and Interaction: Implications for European Reform of Budgetary Rules

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Abstract

EU fiscal rules have been suspended until 2024. European policymakers are considering whether to reinstate the existing fiscal rules or to define a *new framework*. Member States must have enough *fiscal space*. But the *sustainability of public debt* must be safeguarded. We use a nonlinear dynamic model to test if a *primary balance adjustment rule* can preserve debt sustainability in the presence of interactions between fiscal policy, economic growth, and interest rates. We find that a *dynamic* adjustment rule to changes in *debt service* can reduce the equilibrium *debt ratio,* even stabilizing the associated *risk premium*.

1 Introduction

During the pandemic crisis, the fiscal rules of the Stability and Growth Pact (SGP) have been suspended (EC, March 2020). The *general escape clause* invoked by the European Commission allows Member States to take appropriate budgetary measures in the face of *exceptional circumstances*. In May 2023 the European Commission (EC) and the European Council (EUCO) decided that government borrowing limits should

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remain suspended in 2023, because of Russia's invasion of Ukraine slowing down economic growth.[1]

Returning to a strict application of the pre-pandemic fiscal framework in 2024 would require an excessive fiscal adjustment, especially for countries with high debt-to-GDP ratios, hence limiting the space for spending on public investment and the supply of European public goods (Wolf et al. 2021).

A revision of the European fiscal framework should consider at least three macroeconomic developments (Giavazzi et al. 2021). As a *first point*, the current global economic environment is different from the one prevailing thirty years ago when the existing fiscal rules were designed. The current scenario is characterized by low interest rates and a strong demand for safe assets (Habib et al. 2020). Monetary policy has limited ability to achieve macroeconomic stabilization due to the Effective Lower Bound (ELB) on nominal interest rates. Moreover, as the natural rate of interest will remain close to pre-pandemic levels once current inflationary pressures have subsided, the ELB is likely to persist (Rehn 2023). Therefore, there is an inevitable need for coordination between monetary and fiscal policy (Bonatti et al. 2020). Indeed, lower real interest rates reduce the cost of servicing debt, freeing up some fiscal space. At the same time, the new framework should incentivize Member States to expand the fiscal space during economic booms (Blanchard et al. 2020).

The *second development* is the launch of *Next Generation EU (NGEU)*. As far as European governance is concerned, the experience of National Recovery and Resilience Plans (NRRP) has shown the potential of the EU in collecting resources for growth-oriented public investments. This emphasizes the capacity for cooperation between national governments and European institutions to exploit the complementarity between national investments and collective growth and to determine critical areas of intervention (e.g., green and digital transitions) for common EU policy goals. The market experience with NGEU confirmed the existence of a strong demand for European debt instruments (Amato et al 2021; Amato and Saraceno 2022).

Finally, the *third development* is the need for significant spending capacity if EU countries are to meet the targets set in many strategic areas in the coming years (Čavoški 2020). So, the suspension of fiscal rules until the end of 2023 offers a great opportunity to define a new *European fiscal contract* to address these challenges. Obviously, the *new rules should preserve the primary objective of debt sustainability* but, at the same time, they must allow for a stronger stance in favor of economic growth, which, in the long run, is crucial for sustainability.

These strategic aspects give rise to a lively debate for redefining the EU budgetary rules. It spans however two different levels. The first one is about the development of a *fiscal union*, characterized by increased risk sharing and a consistent EU budget (Demertzis and Wolff 2020). The second one concerns the fiscal rules imposed on Member States (Blanchard et al. 2020). These two dimensions are related, but independent.

This paper addresses the latter issue by focusing on the relationship between *fiscal rules* and *public debt sustainability*. To investigate the topic, we remove the standard assumption that the GDP growth rate, real interest rate, and primary budget balance

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[1] https://ec.europa.eu/commission/presscorner/detail/en%5E/speech_22_3269.

are *exogenous* parameters of the government's intertemporal budget constraint. We warn of the existence of *interaction* and *endogeneity* between these variables and of the adverse effects of potential *nonlinearity* in response to fiscal policy. Notably, these endogeneities have important implications for debt sustainability. Mainly, we find that a *primary balance adjustment rule* to protect against a potential return of the *snowball effect* would be effective but difficult to implement. Specifically, we show that if the government's budget adjusts in response to changes in debt service, the equilibrium level of government debt decreases substantially and so does the volatility associated with equilibria. Finally, such an adjustment mechanism also has a stabilizing effect on the possible chaotic dynamics associated with rising *risk premiums*. In this view, our approach extends the analysis of Blanchard (2023) who tested the effectiveness of this rule in reducing the uncertainty associated with $(r - g)$.

The paper is organized as follows. Section 2 presents the standard model of public debt. In Sect. 3 we briefly focus on the role of uncertainty. Section 4 introduces a simple nonlinear dynamic model of public debt sustainability. Section 5 explores the main proposals to reform EU fiscal rules. Finally, Sect. 6 concludes with some policy implications.

2 The Standard Model of Public Debt

The dynamic of public debt is given by the following *accounting relationship*:

$$B_t - B_{t-1} = r B_{t-1} + D_t \tag{1}$$

where B_t is the real value of the stock of debt at the end of period t, B_{t-1} is its lagged value (the value of debt one year earlier), r is the real interest rate and D_t is the value of the primary balance deficit of the government, defined as non-interest spending minus taxes (*ceteris paribus*, a negative primary balance increases the stock of debt).[2] However, the relevant index for *debt sustainability* is the debt-to-GDP ratio (B_t/Y_t).[3] We define the growth rate of output g so that $g \equiv (Y_t - Y_{t-1})/Y_{t-1}$. Then, dividing both sides of (1) by Y_t and rearranging we get:

$$b_t - b_{t-1} = \frac{(r - g)}{(1 + g)} b_{t-1} + d_t \tag{2}$$

where $b_t \equiv B_t/Y_t$ is the *debt ratio*, and $d_t \equiv D_t/Y_t$ is the ratio of the primary balance (deficit) to GDP. Equation (2) is the *dynamic equation of public debt*. Note that the term $(1 + g)$ is not relevant to the discussion. In fact, as g is typically small, $(1 + g)$ is

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[2] The overall deficit is given by $(r B_{t-1} + D_t)$. This means that the official deficit (measured with i) must be corrected for the difference between the nominal and the real interest rate, which is equal to the inflation rate. This correction is all the more important the higher the inflation rate.

[3] A more relevant index for debt sustainability is the *debt-to-fiscal revenue ratio*. This ratio *directly assesses* the government's ability to generate revenue to meet debt obligations. In addition, it reflects budgetary constraints, thus providing a more comprehensive measure than the debt-to-GDP ratio. However, since the latter has remained stable in advanced economies over the past 20 years (IMF 2021a, b), focusing on the *debt-to-GDP ratio* has the same implications (Stoilova and Patonov 2013).

very close to one, so that in continuous time this term disappears. Thus, changes in the debt ratio depend essentially on *two factors*: (i) the ratio of the primary balance d_t; and (ii) the product of the (lagged) debt ratio with $(r − g)$, the so-called *snowball effect*: assuming a balanced primary budget, debt increases at the pace of the real interest rate r, output increases at the pace of g, so the debt ratio increases by $(r − g)$.

The standard discussion of debt dynamics assumes that $(r − g)$ is *positive*. This means that, to stabilize the debt ratio, the government must run a primary surplus $(s_t = −d_t)$. To stress this fact, we insert the equilibrium condition $b_t = b_{t−1} = \overline{b}$ in (2). The required stationary primary balance surplus, $\overline{s}$, is given by:

$$\overline{s} = \frac{(r − g)}{(1 + g)}\overline{b} \tag{3}$$

Now, the larger the debt ratio $\overline{b}$, the larger the required primary surplus $\overline{s}$. Therefore, if the government runs a deficit and increases the debt ratio at some point, a larger primary surplus must be obtained in the future to stabilize it. In other words, if the government does not raise taxes or reduce spending, the debt ratio will explode, with $\underline{b} \to \infty$, *which is not realistic*.

Now suppose, as it is the case for many advanced economies, that $(r − g) < 0$.[4] The value of the primary balance needed to stabilize the debt is defined by Eq. (3). This implies that the government is not required to run a primary surplus but may run a *primary deficit* instead $(\overline{s} = −\overline{d} < 0)$. Further, the larger the debt ratio $\overline{b}$, the larger the deficit $\overline{d}$ the government can run while keeping the debt ratio stable. The debt ratio in this case will *always converge* to $\overline{b} = \overline{s}(1 + g)/(r − g)$, which is equal to or greater than zero.

How should we economically interpret $(r − g) < 0$? The government pays an interest rate on the issued debt equal to r, so that the total expenditure on interest is equal to rb_t. However, as output increases at the rate g over time, the government can issue new debt each year in the amount gb_t, thereby keeping the debt ratio constant. If g exceeds r, revenues from new issues exceed interest payments. Moreover, the higher the debt, the larger the difference. Thus, if debt sustainability is intended along the lines of "debt following a convergent trajectory" (Abbas et al. 2019), under the assumption that $(r − g) < 0$, any permanent primary deficit can be financed by a sustainable public debt, conditioned on the capacity (and the willingness) of investors to hold public bonds. In other words, the government has a (potentially) infinite "fiscal range".

However, the idea of non-explosive debt may be a purely theoretical matter. In fact, if $(r − g)$ is close to zero, and the government has a large primary deficit, the debt may converge to a very high level. In practice, such an increase may be indistinguishable from an actual explosion.[5] Table 1 shows the different cases. The last column of

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[4] Notice that a long run $(r − g) < 0$ induces *dynamic inefficiency* which is typically associated to an over-accumulation of productive capital. Rational bubbles on speculative assets (Tirole 1985) or additional non-productive debt contribute to reduce capital accumulation and restore dynamic efficiency i.e.: $(r − g) \geq 0$.

[5] For this reason, Timbeau et al. (2021) proposed a definition of *public debt sustainability* based on the possibility of conducting a *fiscal effort* to achieve a public debt target within a given time horizon.

Table 1 Debt evolution in the standard model of public debt ($b_0 = 100$). Source: Authors' calculation

Panel(a): (r − g) < 0, $d_t = 0$					Panel(b): (r − g) > 0, $d_t = 0$					Panel(c): (r − g) < 0, $d_t > 0$				
r (%)	g (%)	(r − g)	d_t	$\bar{b}$	r (%)	g (%)	(r − g)	d_t	$\bar{b}$	r (%)	g (%)	(r − g)	d_t	$\bar{b}$
3	3	0.000	0	n.d	3	3	0.000	0	n.d	3	3	0.000	0.1	inf
2.5	3	− 0.005	0	0	3	2.5	0.005	0	inf	2.5	3	− 0.005	0.1	20
2	3	− 0.010	0	0	3	2	0.010	0	inf	2	3	− 0.010	0.1	10
1.5	3	− 0.015	0	0	3	1.5	0.015	0	inf	1.5	3	− 0.015	0.1	7
1	3	− 0.020	0	0	3	1	0.020	0	inf	1	3	− 0.020	0.1	5

The initial value of the debt ratio (b_0) was set at 100%. Panel(a): (r − g) < 0 and balanced government budget; Panel(b): (r − g) > 0 and balanced government budget; Panel(c): (r − g) < 0 and government running a primary deficit. In the first case the public debt always *decreases*, in the second case it always *increases*, in the third one it *may increase or decrease*, but still does not explode
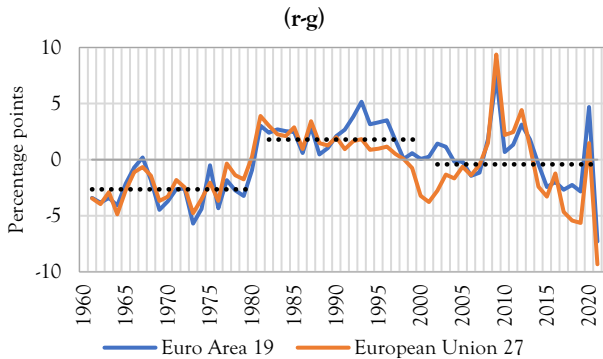
n.d. not defined; *inf* infinity

(r-g)

Fig. 1 $(r - g)$ in the Euro Area 19 and the European Union 27 (1960–2022). *r* is proxied by the real long-term interest rate and *g* by the growth rate of GDP at 2015 reference levels. The *zero line* is superimposed in grey. The *dotted black lines* represent the averages 1960–1980 (characterized by $r - g \ll 0$), 1980–2000 (characterized by $r - g > 0$) and 2000–2022 (characterized by $r - g < 0$), respectively. Source: Authors' calculation on AMECO data

Panel(c) is *emblematic*: given a positive deficit, small variation in *r* and *g* lead to different debt ratios ($\bar{b}$) in equilibrium.

These results challenge the traditional discussion on public debt, which is seen as a "burden on the shoulders of our grandchildren", who will have to repay it with an inevitable increase in (future) taxes (Feldstein 1974; Buchanan and Wagner 1977; Heilbroner and Bernstein 1989; Kotlikoff 1992).[6]

According to this analysis, the IMF outlook (April 2022) forecasts that 18 out of 30 advanced economies will have decreasing debt ratios by 2027, with debt ratios increasing by more than 5 percentage points only in 3 of the countries considered by the study, namely Belgium, South Korea, and the United States. Similarly, the EC (October 2022) noted that public debt fell to 94.2 percent of GDP in the Euro Area, after a high of 98.3 percent at the end of the second quarter of 2022 (EC 2022). Therefore, on the one hand, there are concerns that although debt ratios are expected to stabilize at pre-pandemic levels in the next years, they will remain *excessively high*. On the other hand, the focus is on *historically low real interest rates*. The main argument is that, once recovery is underway, real interest rates will remain well below GDP growth rates (Moreno Badia et al. 2021). Indeed, despite recent increases in nominal interest rates, real interest rates are remarkably low in advanced economies (Caballero et al. 2017). And if the secular drivers of *r* are structural, a reversal in a few years seems unlikely (Rehn 2023). In this perspective, negative interest-growth differentials $(r - g)$ will continue to be the norm, playing in favor of public debt sustainability (Fig. 1).

Except for 2008–2013 and 2019–2020—reflecting the *sharp contraction* in output because of the global financial crisis first and the Covid-19 crisis later—the average

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[6] Similarly, these results question the advice of Count Mirabeau to the King of France, that "public debt" is a way of drawing bills on posterity since it consumes wealth before it is produced. So that "as soon as the state borrows money, a new tax exists, whether it is declared or not, to obtain the guarantee of the debt made today" (Mirabeau 1787).

$(r - g)$ over the last 30 years has been negative for most EU economies. However, despite the simplicity of the standard model, it is difficult to draw general conclusions by focusing on aggregate time series. Indeed, in terms of the (average) size of r, g, Δd and Δb significant differences emerge between individual countries, within and outside the Eurozone (Table 2).

Table 2 Real interest rate, growth rate of GDP and change in deficit and debt ratio (1995–2022). Source: Authors' calculation on AMECO data

Country	1995–2022				
	r	g	$(r - g)$	Δd	Δb
Austria	1.42	1.69	− 0.27	0.17	0.33
Belgium	1.50	1.76	− 0.26	0.00	− 0.85
Bulgaria	− 0.53	2.17	− 2.69	0.11	− 2.72
Croatia	2.21	2.25	− 0.04	− 0.05	1.82
Cyprus	3.13	2.69	0.44	0.02	1.42
Czechia	0.94	2.34	− 1.40	0.30	1.09
Denmark	1.19	1.66	− 0.47	0.15	− 1.40
Estonia	1.49	4.04	− 2.55	− 0.17	0.55
Finland	1.39	2.06	− 0.66	0.15	0.41
France	1.74	1.55	0.19	0.07	1.89
Germany	1.53	1.25	0.28	0.30	0.34
Greece	5.06	0.89	4.17	0.31	2.91
Hungary	1.17	2.58	− 1.40	0.13	− 0.29
Ireland	1.67	6.00	− 4.34	0.09	− 1.19
Italy	2.16	0.55	1.62	0.10	0.98
Latvia	− 0.14	3.68	− 3.82	− 0.06	1.17
Lithuania	0.99	4.10	− 3.11	− 0.03	1.13
Luxembourg	− 0.02	3.27	− 3.28	− 0.09	0.54
Malta	1.07	3.93	− 2.86	− 0.04	0.91
Netherlands	1.09	1.97	− 0.88	0.24	− 0.79
Poland	2.48	3.93	− 1.45	− 0.01	0.08
Portugal	2.28	1.37	0.91	0.15	1.89
Romania	− 0.17	3.05	− 3.22	− 0.15	1.64
Slovakia	1.14	3.46	− 2.32	0.03	1.31
Slovenia	1.16	2.74	− 1.57	0.17	1.94
Spain	1.76	1.88	− 0.11	0.09	1.86
Sweden	1.44	2.37	− 0.93	0.27	− 1.36
Euro Area 19	1.60	2.57	− 0.97	0.08	0.88
European Union 27	1.45	2.56	− 1.11	0.08	0.58

Average annual values (percent or percentage points)

To sum up, debt dynamics are *more favorable* when $(r - g) < 0$. However, there are (at least) two additional factors that are not considered by a debt sustainability analysis based on the intertemporal budget constraint. The first is *uncertainty*. In fact, although the (average) forecasts of $(r - g)$ are negative over a long period of time, these predictions are subject to wide confidence intervals (Blanchard et al. 2023). The second is the *interaction* and *endogeneity* among r, g and d. Notably, the real interest rate depends on current fiscal policy (Dell'Erba and Sola 2016), and current fiscal policy determines the GDP growth rate in the long run (Klemm and Parys 2015). Hence, deficits are likely to affect the actual interest rate r and eventually debt dynamics, but excessive fiscal consolidation can also directly undermine debt sustainability (Cherif and Hasanov 2018). As a result, even if $(r - g)$ is positive, small changes in its value are enough to undermine the stability of a *nonlinear economic system*. So, *uncertainty*, on the one hand, together with *interactions and endogeneity*, on the other hand, affect debt sustainability in inherently different ways, and their implications for the design of efficient fiscal rules must be considered together.

3 Uncertainty

Let us focus on the role of *uncertainty* in affecting the stability of the factor $(r - g)$. This issue has been deeply studied by Blanchard (2019, 2023). He stresses that the evolution of the debt ratio depends on the realizations of current and future values of $(r - g)$ and d. Moreover, the dynamics of debt and interest rates are *correlated* because interest rates incorporate *risk premiums* that respond *nonlinearly* to increases in debt. Hence, without an upper bound on the distribution of these variables, the *probability* of debt exploding is small but *different from zero*. For this reason, the literature has dealt with the issue of public debt sustainability with reference to the probability that after a certain number of years the debt ratio will or will not be on a *non-converging trajectory*.

The IMF and the EC have developed their own macroeconomic models to conduct *stochastic* public Debt Sustainability Analyses (DSA) as a tool for assessing risks to public debt sustainability (Di Bella and Gabriel 2008; Bouabdallah et al. 2017; Alcidi and Daniel 2018). DSA models are also behind the EC's legislative proposal to replace numerical rules with structured processes that broadly consider the determinants of debt risks (European Commission 2022; Heimberger 2023). It is useful to review this approach following Blanchard (2023). The role of uncertainty and the effectiveness of adjustment rules on the government's budget balance can be studied by assuming that $(r - g)$ is the sum of a *random walk*, x, a constant α, and a white noise term ε_u

$$(r - g)_t = \alpha + x_t + \varepsilon_u$$

$$x_t = x_{t-1} + \varepsilon_x \tag{4}$$

In Eq. (4), shocks to $(r - g)$ are pure random values that follow a normal distribution with mean equal to zero and specific standard deviations, i.e., $\varepsilon_x \sim N(0, s_x)$ and

$\varepsilon_u \sim N(0, s_u)$. This reflects the idea that while the expected future $(r - g)$ is equal to its value today, it may increase or decrease over time, *permanently* or *temporarily* (if ε_x or ε_u are involved, respectively). Recalling the debt accumulation equation, where the usual approximation $(1 + g) \approx 1$ applies, variations in the debt ratio are equal to:

$$b_t - b_{t-1} = (r - g)_t b_{t-1} + d_t \tag{5}$$

Finally, the primary budget balance of the government d_t consists of a constant β plus a white noise ε_d. In this context, a *simple fiscal rule* can require that the *government's primary budget* adjusts to changes in r and g and thus to *debt service* $(r - g)_t b_{t-1}$. Notably, in this formulation, ε represents the intensity of the adjustments. Therefore, by varying this parameter, different scenarios corresponding to different *adjustment efforts* by the government can be simulated. The higher ε, the more public deficit will react to changes in $(r - g)$:

$$d_t = (\beta + \varepsilon_d) + \varepsilon \underbrace{\left[(r - g)_t b_{t-1}\right]}_{debt\ service} \tag{6}$$

where $\varepsilon_d \sim N(0, s_d)$, and ε_d is uncorrelated with ε_u and ε_x. The benchmark case in which there is *no feedback* is obtained by setting $\varepsilon = 0$. Alternative scenarios are computed by calculating the probability distribution of the debt ratio 10-years ahead for different values of ε.

We assume that b_0 (the value of debt in the initial period) is equal to 100% of the GDP, and that the primary balance is $\beta = -1\%$ (i.e., an average *structural deficit* of one percent). Together with the assumption that $= -1\%$ (i.e., an average $g > r$ in the white noise process), this implies that under *certainty* the debt ratio *remains constant*. The increase in debt by year 10 represents a measure of *debt convergence*. Figure 2 shows our own simulations of the model. The distribution of the debt ratio is based on 500.000 draws for $\varepsilon_x, \varepsilon_u, \varepsilon_d$.
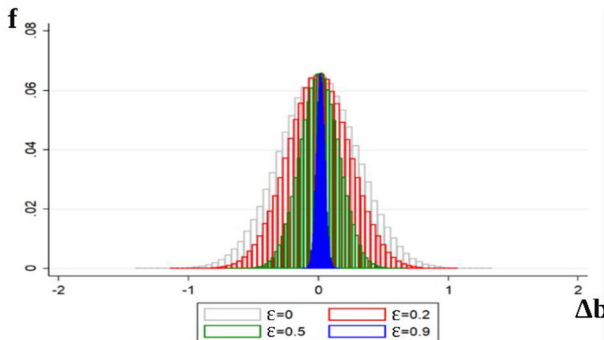

Fig. 2 Debt distribution in a Stochastic Debt Sustainability Model, as in Blanchard (2023). The following calibration was used: $\alpha = -1\%$ (white noise constant in the distribution of r − g), $\beta = -1\%$ (constant of the budget balance), $s_x = 5\%$ (s.d. of the random permanent component of r − g), $s_u = 0.5\%$ (s.d. of the random temporary component of r − g). The gray, red, green and blue distributions represent different efforts to adjust the budget balance to debt service. Source: Authors' own simulation

Under the assumption that $\varepsilon = 0$ the outcome is given by the distribution in grey (the other three cases—in red, green and blue—correspond to positive and increasing values of ε). Note that in the baseline scenario, the probability (p) that the increase in the debt ratio over ten years exceeds 10% is 2.6%. On the other hand, with $\varepsilon = 0.2$, the distribution of the debt ratio after 10 years is narrower, and the probability of a debt increase of more than 10% is only 0.9%. Then, with $\varepsilon = 0.5$, the same probability falls to 0.02%, and is virtually zero when $\varepsilon = 0.9$.

To conclude, uncertainty introduces a crucial argument for the use of *automatic adjustment rules* to control the debt ratio. In fact, these mechanisms reduce the probability of *debt explosion* due to adverse changes in r and g (Blanchard 2023). However, as we will show in the next section, the validity of a fiscal rule must also be assessed in relation to its ability to reduce the risk of default in the presence of potential *endogeneity* and *nonlinearity* among the variables affecting the debt ratio. A *dynamic analysis* has the advantage of considering the interaction between fiscal policy, economic growth, and the real interest rate. This highlights further forms of uncertainty and makes the design of budgetary rules more *complex*.

4 Nonlinearity and Endogeneity

The literature on public debt sustainability has investigated the effect of nonlinearities starting from the government's *intertemporal budget constraint*. Bohn (1998, 2008) employs a quadratic function to model the *accounting relationship* in the US and finds that the primary surplus is more responsive to increases in debt at higher debt levels. By contrast, Abiad and Ostry (2005), focusing on an international sample of advanced economies, find that the response of the primary balance to debt weakens at higher debt levels. Ghosh et al. (2013) are the first to explore the debt sustainability implications of a nonlinear response of the primary balance to rising debt ratios. They estimate a nonlinear *fiscal reaction function* for 23 advanced economies over the period 1970–2007 and use it to compute "fiscal space", defined as the gap between current debt ratios and estimated debt limits. However, as argued by Ghosh et al. (2013, p.5), debt *sustainability analysis* "could be enriched by allowing the output growth rate to be a function of the level of debt and or the real interest rate, […] this complicates the theoretical analysis (because of the potentially nonlinear effect of the feedback between debt, interest rates and growth in the model's equilibrium)". The *endogenous* nature of r and g in Eq. (2) makes the dynamics of the debt ratio more realistic *but unpredictable in some scenarios* (Bischi, et al. 2022).

There are several theoretical reasons for using an endogenous relationship to describe the dynamics of public debt. For instance, in *overlapping generation models*, public debt reduces savings and capital accumulation, thus weakening the growth rate of GDP in the long run (Diamond 1965; Blanchard 1985). Similarly, in *endogenous growth models*, public debt may have a negative effect on economic growth (Barro 1990). Accordingly, Mendoza and Ostry (2008) show that governments respond to rising public debt by increasing the primary surplus or reducing the deficit. However, they exhibit "*fiscal fatigue*", so their ability to improve primary balances may not be able to keep pace with rising debt levels (Ghosh et al. 2013; Checcherita-Westphal and

Ždarek 2017). Further, a high debt ratio limits the effectiveness of public spending on growth, creates uncertainty and may be associated with sovereign yield spreads and lower private investment (Laubach 2009; Cochrane 2011; Teles and Mussolini 2014).

In addition, there are several reasons to believe that the debt-growth relationship can be better captured by a *nonlinear function*. For instance, the asymmetric effects of fiscal policy could motivate a nonlinear impact of public debt on GDP growth (Perotti 1999). Nonlinearities in the debt-growth nexus may also arise when there is a *no return limit* for fiscal sustainability. In fact, an excessive debt ratio may have negative effects on investment decisions (Krugman 1988). Alternatively, as the debt ratio increases, creditors may demand higher interest rates to compensate for the risk of default, thus restricting aggregate investment (Greenlaw et al. 2013). A large strand of empirical literature supports this view (Cecchetti et al. 2011; Checherita-Westphal and Rother 2012; Woo and Kumar 2015). Recently, Eberhardt and Presbitero (2015) empirically analyzed the long-run relationship between public debt and growth in a large panel of countries and found a *significant nonlinear* relationship across countries, but no evidence of common debt thresholds within countries over time.

On the theoretical ground, a similar problem is addressed by Bischi et al. (2022). They endogenize the standard model of public debt to highlight the potential nonlinearities in the relationship between the debt ratio, the real interest rate and the GDP growth rate. Exploiting this framework, the authors study the conditions under which government bond sales (de)stabilize the debt/GDP ratio and the real interest rate. They show that an indebted economy can easily shift towards repulsive regions even for negligible and *transitory shocks* in some of its behavior parameters. Thus, there may exist potential thresholds beyond which an indebted economy drives towards default, even moving from a *stable equilibrium*.

Another problem connected with nonlinearity in the real interest rate is related to *self-fulfilling beliefs* (Calvo 1988). Interest rates are assumed to reflect macroeconomic fundamentals. Yet, sovereign debt markets are prone to sudden shifts where investors start to demand wide spreads even in the absence of major changes in macroeconomic fundamentals. Therefore, in addition to a "good" equilibrium, a "bad" equilibrium may exist, characterized by a higher interest rate and a higher debt ratio (*sunspot equilibrium*). Specifically, when public debt is considered safe, the government can borrow at a safe rate and its debt ratio is sustainable. If, however, investors begin to worry about the risk of default and start demanding a risk premium to hold its bonds, rising interest rates and worsening debt dynamics increase the *probability of default*, potentially triggering this outcome (Conesa and Kehoe 2017; Bocola and Dovis 2019). As became clear during the European debt crisis, the dynamics in which investors seek to abruptly exit the market, causing sharp rate hikes and triggering sovereign defaults, are not new in the macroeconomic landscape (Corsetti et al. 2014).

Remarkably, the problems related to nonlinearities are different, but the policy implications are quite similar. To say, a lower debt ratio implies a smaller adverse effect of the real interest rate on debt dynamics. Therefore, stricter fiscal discipline for Member States is desirable. If the debt ratio is low enough, even if investors demand a higher risk premium, the dynamic of public debt would be sustainable and there would be no negative equilibrium under the assumption of rational expectations. Therefore,

the *credibility of fiscal rules* is crucial to avoid the emergence of *sunspot equilibria* or potential shifts to regions of *chaos* or *non-sustainability* (Guirola and Pérez 2022).

4.1 A Benchmark Model

Traditionally, the standard model of public debt is composed by a single first-order linear difference equation in b_t if r, g and d are *exogenous parameters* (Alesina and Perotti 1995; Neck and Strum 2008). However, the analysis can be extended to consider *endogenous dependencies* between the variables.

To illustrate the case, we study a *nonlinear* dynamic model with two first-order difference equations as a benchmark:

$$b_t - b_{t-1} = b_{t-1}(r_{t-1} - g) + d$$
$$r_t - r_{t-1} = \alpha arctg(b_{t-1} - \overline{b}) + \beta(\overline{r} - r_{t-1})^3 \tag{7}$$

where:

$$g = \overline{g} + \gamma d - \delta(r_{t-1} - \overline{r})$$
$$d = \mu - \varepsilon(r_{t-1} - g)b_{t-1} \tag{8}$$

The first equation in (7) is the *government's intertemporal budget constraint*. However, contrary to the standard model, the second equation of the system captures the dynamic evolution of the *real interest rate* over time $(r_t - r_{t-1})$, which is now considered *endogenous* depending on both the actions of the *central bank* $\beta(\overline{r} - r_{t-1})^3$ and *financial markets* $\alpha arctg(b_{t-1} - \overline{b})$. The idea is that the spread between the actual indebtedness level of an economy (b_{t-1}) and the level of indebtedness considered as sustainable by investors $(\overline{b})$ can be seen as a proxy for the *risk premium* – the component $arctg(b_{t-1} - \overline{b})$. In this scenario, the debt ratio and the real interest rate move together, and the $arctg$ function captures this empirical relationship, which is subject to a ceiling due to the intervention of the central bank—at some point—to contain the emergence of *sovereign spreads* (*see* Roch and Uhlig 2018; Ernst et al. 2017 who were the first to use this functional form). Alongside this, the real interest rate can be set by the central bank in line with its policy objectives. In this perspective, the term $\beta(r_{t-1} - \overline{r})^3$ is a simple *Taylor rule*[7] that guides central bank *monetary policy* in response to variations in economic conditions, and $\beta > 0$ measures the speed of adjustment of financial markets (*see* Carlstrom and Fuerst 2016 who estimate this relation in the US).[8] The cubic exponent captures the speed of adjustment when the interest rate deviates from the target value: once inflation approaches a certain threshold, the CB "adjusts its policy-rule and begins to respond *more forcefully*" (Petersen 2007).

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[7] Following Taylor (1993), the natural interest rate will be the target rate when the level of output is equal to its potential value and inflation is equal to its desired level.

[8] The exponent of the *Taylor rule* provides the *adjustment cost of monetary policy*. For a value of 1, the cost is a linear function of deviations from its fundamental value, while for a value of 3, the function is cubic. In the latter case, the reaction of the CB to deviations of the real interest rate occurs smoothly to avoid destabilization of financial markets and, ultimately, the debt ratio (Bischi et al. 2022).
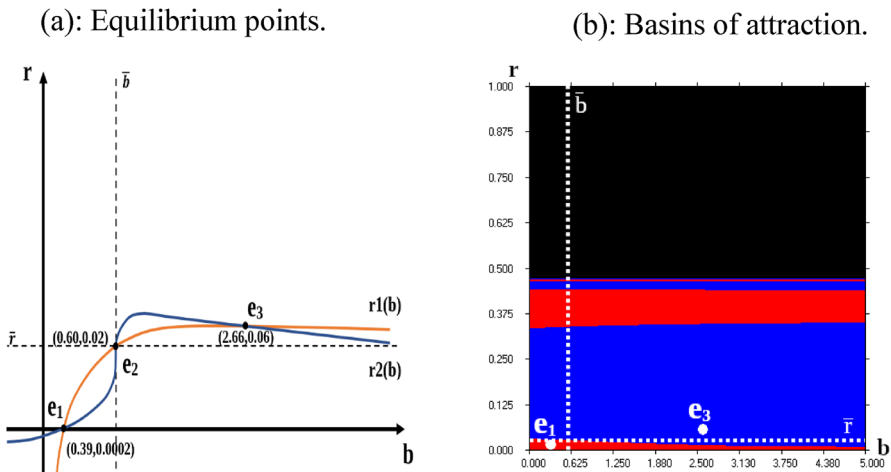
(a): Equilibrium points.

(b): Basins of attraction.

Fig. 3 Public debt and the coexistence of multiple equilibria. The model is simulated with the following parameter values: $\alpha = 0.0005$, $\beta = 10$, $\bar{b} = 0.6$, $\delta = 0.1$, $\varepsilon = 0.01$, $\gamma = 1.5$, $\bar{g} = 0.03$, $\mu = 0.03$, $\bar{r} = 0.02$. The *basins of attraction* of the first (stable) equilibrium e_1 are shown in red and those of third (stable) equilibrium e_3 in blue. The second equilibrium e_2 is *unstable* (i.e., a saddle point) and located along the boundary of the basin of attraction between e_1 and e_3 (Appendix A1). The *black area* represents *non-converging trajectories*. Source: Authors' own simulation

The model is closed with two additional equations which describe the *long-term GDP growth* and a *fiscal policy* rule, respectively. GDP growth is assumed to vary along its long run trend ($\bar{g}$) in response to changes in the budget deficit[9] and the output gap (proxied by the difference between the real and the natural interest rate), while the primary balance d is, as in the model with uncertainty, composed by a constant (μ) and a *fiscal rule* which captures *primary deficit adjustments* to changes in *debt service*, $\varepsilon (r_{t-1} - g)b_{t-1}$. Again, the parameter ε measures the intensity of the *adjustment efforts*.

This model is used to study the interactions between *risk premia* and *fiscal policy*. Notably, in such a framework, changes in some of the parameters cause nonlinear responses of the economy, even chaotic ones, which make it alarming if the debt ratio exceeds some *critical thresholds*.

The time evolution of the *debt ratio* and the *real interest rate* is obtained by the iteration of a *two-dimensional nonlinear map* T: $(b_t, r_t) \rightarrow (b_{t+1}, r_{t+1})$. Equilibria (or stationary situations) are obtained from (7) by setting $b_{t+1} = b_t = \bar{b}$ and $r_{t+1} = r_t = \bar{r}$, in the first and the second dynamic equation, respectively.[10] Equilibrium points are located at the intersections of the two curves (Fig. 3a), while their *basins of attraction* are depicted in Fig. 3b.

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[9] We thank an anonymous referee for pointing out that the long-run effects of fiscal policy are still disputed. In this perspective, the parameter γ will be small when a *neoclassical dynamic* prevails (as GDP growth will be predominantly exogenous and determined by $\bar{g}$) or larger when an *endogenous growth dynamic* prevails. To set the magnitude of the long-run multiplier of government spending on the GDP growth rate, we refer to Geli and Moura (2023).

[10] See Appendix A1 for mathematical derivation of the *equilibrium curves* of the nonlinear map in (7).

Several parameters, namely α, β, γ, δ, ε, μ, $\bar{b}$, $\bar{g}$, $\bar{r}$, characterize the dynamic of the model. $\bar{b}$ and $\bar{r}$ as *policy parameters*. The value of some parameters are obtained from *historical data*: for example, the GDP growth rate ($\bar{g}$) and the exogenous component of budget balance ($\bar{\mu}$) reflect the average value of EU countries over the period 1995–2023. Finally, we rely on the *literature* for the value to the remaining parameters. Based on Carlstrom and Fuerst (2016), IMF (2023), Alcidi and Daniel (2018), Brand and Mazelis (2021) and Jordà et al. (2020), we set $\alpha = 0.0005$, $\beta = 10$, $\delta = 0.1$ and $\gamma = 1.5$, as reference values.[11] Further, we assume that $\varepsilon \in [0.01-0.15]$, which is a sufficiently large interval to test our main fiscal policies.

A standard scenario is characterized by the presence of two (stable) equilibrium points (e_1 and e_3) with $b > 0$, and an intermediate equilibrium (e_2) acting as a separator for their *basins of attraction* (i.e., a saddle point) (Fig. 3a). However, cases with more than two equilibria, as well as one or no equilibria at all may exist, depending on the value of the parameters (*see* Appendix A1 where we calculate the *eigenvalues* of the equilibrium points and report a local stability analysis). These equilibrium points with positive debt ratio are associated with either *low* or *high* corresponding equilibrium values of the real interest rate, i.e., r_1 (0.02) or r_2 (0.06) (where the latter contains a *higher risk premium x, $r_2 = r_1 + x$*).

Figure 3b shows the basins of attraction for the same parameters' constellation used in Fig. 3a. The basin of the stable equilibrium e_1 is represented by the *red region*, whereas that of the stable equilibrium e_3 is represented by the *blue region*. In contrast, the *black region* represents the basin of *divergent trajectories*, i.e., the set of initial conditions (b_0, r_0) that generate time evolutions of the debt ratio leading to *default*. The border separating these two basins is the stable set of the saddle point e_2 (Mira et al. 1996). The structure of the basins shown in Fig. 3b highlights an important feature of nonlinear dynamic models with *coexisting attractors*. Indeed, small shocks to the system do not produce permanent effects if they are confined within the basin of attraction of a locally stable equilibrium, while larger shocks lead to time evolutions that move away from the equilibrium and towards the *coexisting attractor* in the long run. Note that in Fig. 3b, the stable equilibrium basin (e_1) is very *vulnerable* to *exogenous shocks*, due to the narrow area surrounding it, whereas the stable equilibrium basin (e_3) is *more robust* (Bischi and Lamantia 2005).

Numerical simulations provide the effects of various economic conditions or policies on the long-run evolution of the system. The *bifurcation diagrams*, obtained by varying α (Fig. 4a) and ε (Fig. 4b) *ceteris paribus*, represents the impact of an increasing *risk premium* and a more stringent *fiscal policy rule* on the equilibrium debt ratio b^*, respectively.

The left panel of Fig. 4a shows that, starting with a *low debt ratio* (0.6) and a *low real interest rate* (0.015), for reasonable values of α (*as a proxy for the risk premium*) the two stable nodes (e_1 and e_3) remain stable (with their own basins of attraction).

Then, if α increases significantly (a *sovereign debt crisis*), they lose stability through a period-doubling bifurcation after which the long run evolution of the model is characterized by *stable oscillations* of period two with values around equilibrium. However,

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[11] See Table 4 in the Appendix for a detailed description of all model parameters, the value used for simulations, and reference intervals taken from the literature.
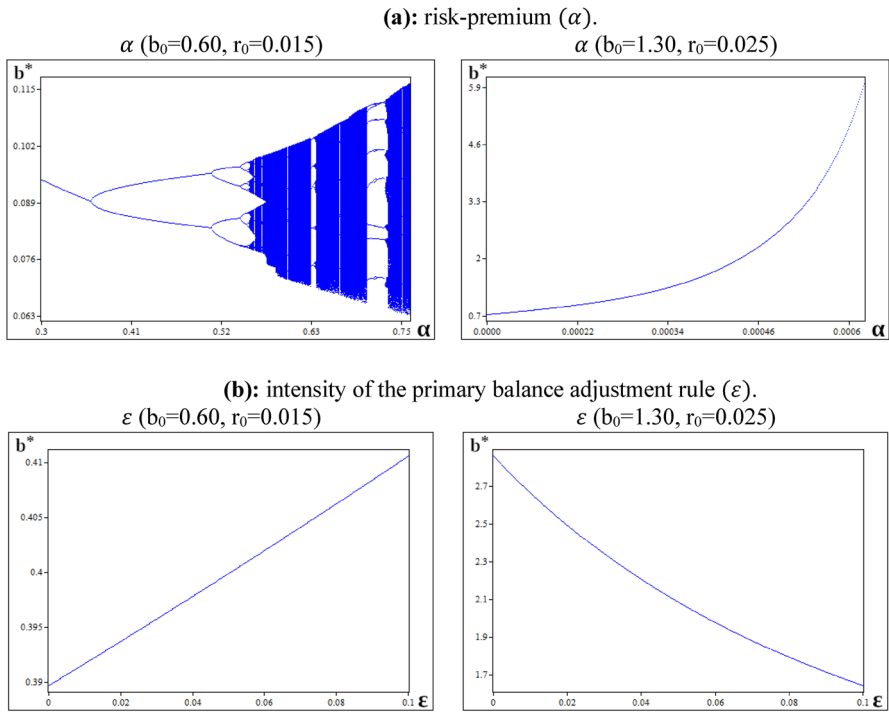
(a): risk-premium (α).

α (b_0=0.60, r_0=0.015) α (b_0=1.30, r_0=0.025)

(b): intensity of the primary balance adjustment rule (ε).

ε (b_0=0.60, r_0=0.015) ε (b_0=1.30, r_0=0.025)

Fig. 4 Uncertainty and transition to chaos: bifurcation diagrams for α and ε. The equilibrium value of the debt ratio b^* (y-axis) is obtained by varying the benchmark parameter (α and ε, respectively) on the x-axis, *given other parameters* of the system. **a** Risk-premium; **b** intensity of the primary balance adjustment rule. In **a**, α is varied between 0 and 0.75 (low-debt panel), and between 0 and 0.0006 (high-debt panel). In **b** ε is varied between 0 and 0.1, in both the low and high-debt panels. Source: Authors' own simulation

for further increases in α, a period-doubling cascade occurs, leading to stable periodic cycles of increasing period, and eventually to *deterministic chaos* (Schuster and Just 2006). The blue vertical segments represent chaotic time patterns of the dynamic variables which, along with a high sensitivity to small shocks of the initial conditions makes predictions complicated.

In addition, the bifurcation diagram shows a further form of *instability*. Indeed, in a range of $\alpha \in [0.36$–$0.50]$, two different attractors coexist, which can be obtained for the same parameter values but starting from *different initial conditions*, i.e., *multistability* (Bischi and Kopel 2013). In other words, high levels of the parameter α generate *instability in the system*. In the right panel of Fig. 4a we simulate the same model but with a *higher debt ratio* (1.30) and a *higher interest rate* (0.025) at t_0. In this scenario a negligible increase in α would lead to *default*. Moreover, the model is only stable for small values of the latter. In fact, by letting α vary between 0 and 0.0006, we obtain that the equilibrium debt ratio ($\bar{b}$) increases from about 0.6 to over 5.3 (i.e., 530%) and eventually *explode*.

The *policy problem* associated with nonlinearities is therefore to prevent the economy from ending up in the "bad" equilibrium (e_3) or to improve its value to make

it more "bearable" for the economy. However, this theoretical problem is associated with a thorny empirical issue. Indeed, we do not know whether several equilibria exist or whether the one observed is the only true steady state. Therefore, the existence of *multiple equilibria* has often been used (in the European narrative) as an argument for reducing debt and the debt ratio from its current levels (Helpman 1989; Gros 2012). A lower debt ratio implies a smaller adverse effect of an increase in the real interest rates on debt dynamics. If the debt ratio is sufficiently low, then even if investors are risk adverse and demand a higher risk premium (through an increase in α), this would not be enough to make the debt ratio *unsustainable*.

In this perspective, the right panel of Fig. 4b shows how an *adjustment rule to debt service* on the primary budget of the government (whose sensitivity to changes in r and g is represented by ε) may reduce the equilibrium level of public debt by significantly lowering the *high-debt equilibrium* (e_3). In fact, if we increase the elasticity of deficit adjustments by a factor of ten (raising ε from 0.01 to 0.1), the *convergence debt ratio* in e_3 decreases from 264 to 164% (*see* the time series of b and $r - g$ in Fig. 8b). At the same time, as shown in Fig. 5, the *low-debt equilibrium* e_1 becomes *more robust*. In fact, while the basin of attraction for the old equilibrium (corresponding to an $\varepsilon = 0.01$) is represented by the dashed white line, the *new basin* (represented by the red area and associated to an $\varepsilon = 0.1$) is considerably larger. Notably, some interest rate-debt ratio combinations that initially converged to the high equilibrium e_3, now
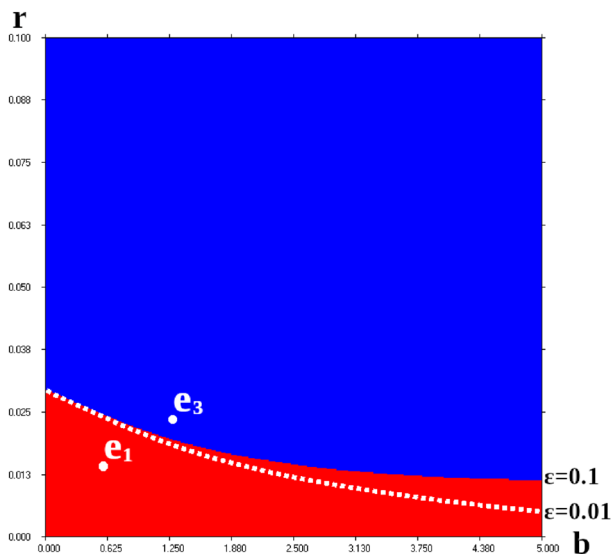

Fig. 5 The effects of an increase in ε on the *basins of attraction* of e_1 and e_3. Same set of parameters as in Fig. 3. The initial debt ratio is plotted on the x-axis in the space 0–5, and the initial real interest rate on the y-axis in the space 0–0.1. An increase in ε (i.e., intensity of the *primary balance adjustment rule to debt service*) from 0.01 to 0.1 increases the *basin of attraction* of the low-debt equilibrium (e_1). Indeed, even starting from higher initial debt values, for a given real interest rate, the dynamic system now converges to e_1 (which is *more robust*). Source: Authors' own simulation
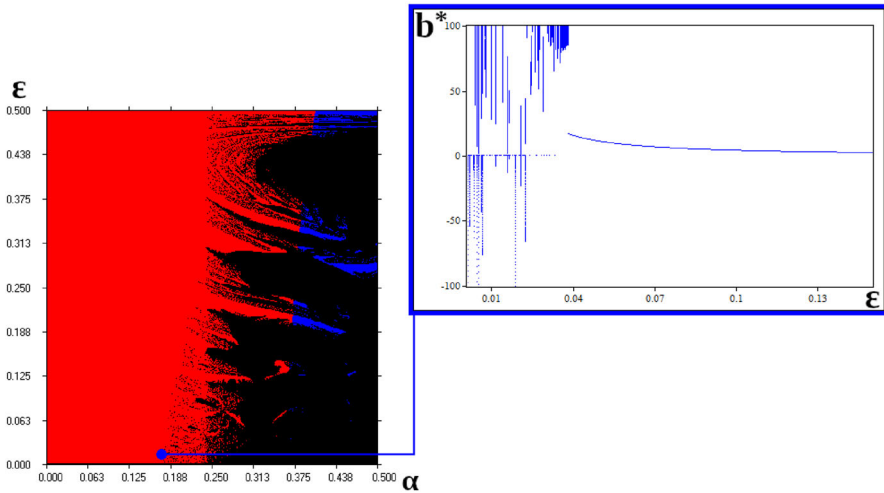
Fig. 6 Two-dimensional bifurcation diagram (for α and ε) and one-dimensional bifurcation diagram for only ε varying with fixed α. Same set of parameters as in Fig. 3. Panel a represents the two-dimensional bifurcation diagram with parameters ε (vertical axis) and α (horizontal axis). In the enlargement we show the transition from instability to stability through changes in fiscal policy (ε). Source: Authors' own simulation

converge to low equilibrium e_1, and the effect is more pronounced as the initial debt ratio increases.

Is there any room for chaos controlling policies in this framework? As far as the effectiveness of the *deficit adjustment rule* is concerned, it should be noted that the definition of an $\varepsilon > 0$ has a *stabilizing* effect on the economic system, even in presence of potential *chaotic dynamics* associated with rising *risk premiums*. This is shown by the two-dimensional bifurcation diagram in Fig. 6.

The first panel of Fig. 6 shows the *two-dimensional bifurcation diagram* for α and for ε. Starting from the parameters constellation of Fig. 3, we let these two parameters vary together to assess their influence on system stability. Red and blue colors identify the areas of low and high debt equilibrium stability, respectively, and black the areas of divergence/chaos.

The second panel of Fig. 6 (on the right) is an enlargement of a small portion of the parameter's basin. This one-*dimensional bifurcation diagram* is obtained by fixing α at 0.00074 and changing ε from 0 to 0.15. Thus, we start from a region of instability for low values of ε and, increasing this parameter, ceteris paribus, we move to a region of stability where the model converges at e_1. It follows that for any level of α, an increase in ε raises the stability of the model. If the government is *more committed* in adjusting its budget balance to changes in the debt ratio, a greater risk premium is sustainable in the economy. Thus, fiscal policy plays a relevant role in stabilizing the system.

Finally, dynamic analysis reveals how the equilibrium debt curve r1(b) is affected by ε. Interestingly, it stretches rightward (and upward) as ε changes (Fig. 9). Hence, a deficit adjustment rule to debt service can (from a theoretical point of view) even cancel

out *multiple equilibria* by *reducing the instability* associated with *nonlinearities*. In the current calibration of the model this happens for $\varepsilon > 0.651$, when the stable node e_1 and the saddle e_2 collide to disappear, giving rise to a *single (stable) equilibrium*.

5 Reforming Fiscal Rules in the EU

The Covid crisis led to the *temporary suspension* of EU budgetary rules, which will probably be *reformed* before being reinstated. Although consultations are ongoing and a decision has not yet been made, there seems to be a *political consensus* to keep the rules, or at least the 3% and 60% thresholds (for *deficit* and *debt*) enshrined in the Maastricht Treaty, but at the same time allow a budget for green investments, at national and EU level, following the example of Next Generation EU.[12] As is well known, when monetary policy is constrained by the ELB, *coordinated fiscal policy* would be optimal, given the higher multipliers of government spending (Christiano et al. 2011; Eggertsson 2011; Woodford 2011). However, the Euro Area lacks a centralized instrument for macroeconomic stabilization and public investment support. This became evident in the pre-Covid period when EU countries with more fiscal space were also those with higher output gaps.

Unfortunately, there is still *no agreement* on a central budget for stabilization purposes or on fiscal transfers between Member States. This raises the question of whether the currency area can ever be truly stable without further integration once Next Generation EU is over.[13] In addition, *European fiscal rules* are not flexible enough to support the necessary long-term investment. Therefore, if no action is taken, there is a serious risk that Europe will not meet its climate goals and will lose competitiveness to other regions of the world.

From a conceptual point of view, designing fiscal rules is far from trivial. A fundamental distinction is made between rules governing the *use of fiscal policy* and rules for *debt sustainability*. The European debate focuses mainly on the latter issue, leaving countries free to follow their *preferred fiscal policy*, while making sure not to raise *sustainability issues* that would directly affect other Member States (i.e., one common objective but several individual paths).[14] This implies that a country may have a lot of *fiscal space*, i.e., may be able to sustain a higher level of debt, but not use it, leaving it for the times ahead. It also introduces an important conceptual issue: fiscal space and debt sustainability depend on both *current* and *planned fiscal policy* (Ghosh et al. 2013; Giavazzi et al. 2021; Blanchard 2023).

To safeguard the objective of debt sustainability, European states have traditionally followed the principles of *budgetary prudence*. This is the result of rules preventing

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[12] See the joint statement of Mario Draghi and Emmanuel Macron in the Financial Times. Financial Times (2021). *The EU's fiscal rules must be reformed*. 23 December 2021.

[13] From Mario Draghi Lecture *in honor of* Martin Feldstein. Cambridge, Massachusetts. 11 July 2023.

[14] As one anonymous referee pointed out, *fiscal sustainability* may be different from *fiscal responsibility*. For instance, a government with a high debt-level could still engage in fiscally irresponsible behavior if in a favorable economic cycle, it decides to increase government debt instead of reducing it. In this case, national commitment can complement European regulation to ensure a responsible use of public spending. That said, in this paper we focus on the concept of *fiscal sustainability* which means sharing fiscal rules so that Member States do not raise issues of sustainability, which would affect other European countries.

deficit spending (i.e., *structural balanced budget rules*), along the lines of the German "Black Zero" (or German "Debt Brake"), but also, the Constitutional Law n. 1/2012 enacted by the Italian Parliament to restore public finances in accordance with the constraints imposed by the Europlus Pact and the Six Pack, as redefined by the Fiscal Compact (Ciolli 2014; Wieland et al. 2018).

However, such rules would *unnecessarily* restrict the fiscal policy of European countries, hampering its use as a macroeconomic instrument or to support public investments (Cerniglia and Saraceno 2022). As a result, EU fiscal rules have been frequently *violated* by Member States and are considered *ineffective* and *difficult to enforce* (Thygesen et al. 2019; Arnold et al. 2022). Therefore, the real challenge is to find new rules that ensure the sustainability of public finances but leave some room for an optimal use of fiscal policy, so that Member States can react to an adverse economic cycle and achieve *domestic macroeconomic stabilization* (Woodford and Xie 2022).

Many proposals to reform the EU fiscal framework have been put forward. Some of them represent *minor improvements* compared to the current framework. These include revising the Maastricht numbers, i.e., maintaining the 60% debt target but relaxing the constraints on the *speed of adjustment* to the target, or raising the target debt level to a more realistic value. Other reforms seek to go a step further, changing spending rules to allow a stronger fiscal response to economic fluctuations, limiting government spending but allowing revenues to move cyclically, more so than with automatic stabilizers (Hauptmeier and Kamps 2022). In a famous Policy Brief of the Brussels-based think tank Bruegel, Darvas and Wolff (2021) show that budget consolidation can be done at a moderate pace in line with EU rules if existing rules are interpreted *flexibly*. Hence, they propose a "green golden rule" to avoid major cuts in public investment. This is in line with the EFB's suggestion of a "modified golden rule" to exclude investment spending on EU co-financed projects from the index used to measure *fiscal compliance* (EFB 2021).

Such an approach would be an improvement on the existing framework and might satisfy the desire of some Member States to return to a strict application of some sort of budgetary rule (Germany and the "frugal" countries) and the flexibility required by other Member States to finance public investment (mainly France and Italy), but it *would be far from an optimal reform* for the EU as a whole (Bofinger 2018).

The analysis of debt dynamics suggests some *general ground principles*. Debt sustainability depends on the ability of a government to generate a primary surplus sufficient to cover debt servicing. In turn, this suggests that rules that make the primary balance endogenous to debt service are more effective in the long run. Since changes in interest rates are rapid, it makes sense that the adjustment of the primary balance follows a principle of gradualism. Likewise, to avoid distortions due to cyclical fluctuations in the 536 economy, it may be useful to define the rule in terms of the cyclically adjusted primary balance (Carnazza et al., 2020)

The second point of the discussion concerns the debt ratio target at 60%. For nearly all EU members, the increase in debt due to the pandemics has made it *unattainable* (Table 3). Empirical analysis has shown that there is no universal threshold beyond which public debt becomes unsustainable (Heimberger 2021). The literature has reported contradictory results also for what concerns the impact of public debt on economic growth. Some intriguing papers argue that there is evidence of a negative

Table 3 Primary budget balance and public debt projections in the EU (2019–2022). Source: Authors' own calculation on AMECO data (Autumn 2022 Economic Forecast)

Country/year	Net lending (borrowing)					General government consolidated debt				
	2019	2020	2021	2022	2023	2019	2020	2021	2022	2023
Austria	0.61	− 8.01	− 5.93	− 3.44	− 2.82	70.63	82.93	82.28	78.46	76.64
Belgium	− 1.94	− 8.97	− 5.56	− 5.22	− 5.83	97.62	112.04	109.19	106.18	107.92
Bulgaria	2.13	− 3.81	− 3.89	− 3.39	− 2.78	20.00	24.55	23.93	22.48	23.61
Croatia	0.22	− 7.31	− 2.59	− 1.55	− 2.35	71.04	86.98	78.39	69.97	67.24
Cyprus	1.27	− 5.77	− 1.70	1.07	1.14	90.43	113.51	101.05	89.59	84.01
Czechia	0.29	− 5.77	− 5.10	− 4.35	− 4.06	30.05	37.66	42.02	42.91	44.23
Denmark	4.13	0.21	3.63	1.76	0.48	33.67	42.21	36.62	33.66	32.77
Estonia	0.12	− 5.47	− 2.41	− 2.31	− 3.73	8.55	18.55	17.60	18.73	19.33
Finland	− 0.95	− 5.53	− 2.69	− 1.39	− 2.32	64.89	74.75	72.37	70.75	71.96
France	− 3.06	− 8.99	− 6.53	− 4.98	− 5.31	97.43	114.96	112.84	111.69	110.82
Germany	1.53	− 4.33	− 3.73	− 2.30	− 3.10	58.93	67.99	68.62	67.43	66.28
Greece	1.15	− 9.93	− 7.45	− 4.06	− 1.84	180.58	206.25	194.54	171.15	161.93
Hungary	− 2.03	− 7.54	− 7.14	− 6.18	− 4.38	65.33	79.30	76.83	76.37	75.21
Ireland	0.47	− 5.03	− 1.66	0.17	0.84	57.01	58.40	55.38	44.73	41.19
Italy	− 1.51	− 9.49	− 7.23	− 5.09	− 3.57	134.14	154.93	150.28	144.61	143.59
Latvia	− 0.57	− 4.34	− 6.98	− 7.09	− 3.41	36.54	41.96	43.59	42.35	44.03
Lithuania	0.47	− 7.03	− 0.99	− 1.86	− 4.42	35.83	46.34	43.67	37.97	41.02
Luxembourg	2.23	− 3.43	0.79	− 0.07	− 1.71	22.38	24.50	24.52	24.27	26.00
Malta	0.59	− 9.37	− 7.78	− 6.04	− 5.73	40.72	53.35	56.32	57.40	59.91
Netherlands	1.80	− 3.71	− 2.61	− 1.07	− 3.96	48.55	54.67	52.43	50.31	52.36

Table 3 (continued)

Country/year	Net lending (borrowing)					General government consolidated debt				
	2019	2020	2021	2022	2023	2019	2020	2021	2022	2023
Poland	− 0.74	− 6.92	− 1.84	− 4.80	− 5.51	45.71	57.17	53.75	51.33	52.91
Portugal	0.12	− 5.82	− 2.90	− 1.93	− 1.14	116.61	134.90	125.54	115.90	109.09
Romania	− 4.33	− 9.24	− 7.11	− 6.54	− 5.05	35.11	46.86	48.86	47.91	47.34
Slovakia	− 1.22	− 5.36	− 5.46	− 4.22	− 5.82	47.97	58.90	62.19	59.59	57.37
Slovenia	0.57	− 7.72	− 4.67	− 3.58	− 5.20	65.42	79.59	74.47	69.94	69.59
Spain	− 3.06	− 10.13	− 6.87	− 4.63	− 4.33	98.22	120.38	118.26	113.95	112.53
Sweden	0.56	− 2.77	− 0.09	0.23	0.18	35.19	39.54	36.33	32.14	29.40
Euro Area 19	− 0.64	− 7.05	− 5.12	− 3.46	− 3.69	85.82	99.03	97.18	93.74	92.47
European Union 27	− 0.54	− 6.73	− 4.63	− 3.36	− 3.57	79.17	91.5	89.42	86.03	84.9

causal effect of higher debt on economic growth (Reinhart and Rogoff 2010). However, other studies, while recognizing the negative association between public debt and (future) growth rates, argue that the evidence of a causal effect between increased public debt and GDP growth is (at best) *weak* (Baum et al. 2013; Panizza and Presbitero 2014; Ash et al. 2020; Jacobs et al. 2020; Heimberger 2021). Moreover, the *critical debt level* depends on several factors, including the *real interest rate*.

In the current EU framework, a country is considered compliant with the "debt rule" if its debt ratio is below 60% of the GDP or if the excess above 60% has declined by 1/20 on average over the previous 3 years (Larch and Malzubris 2022). From this perspective, it would be a mistake to maintain both the target value and the adjustment to the target, and the theoretical arguments suggest that the emphasis on the latter should be reduced (Blanchard et al. 2023). Indeed, while a high debt ratio does not necessarily have a negative effect on GDP growth, unnecessary austerity has detrimental effects on the equilibrium debt ratio (Gros and Maurer 2012; Mazzolini and Mody 2014).

In essence, the dynamic nature of the debt ratio is characterized by a *unit root* (Uctum et al. 2006). This empirical fact provides an argument for limiting its movements through a feedback coefficient (Blanchard 2023). One reason is that there is, for economic and political factors, an upper limit to the primary surplus (i.e., the *fiscal effort*) that the government can sustain (Ghosh et al. 2013; Checherita-Westphal and Ždarek 2017). This fact, along with the distribution of $(r - g)$ eventually leads to an *upper limit on debt* (Mehrotra and Sergeyev 2021). Moreover, high public debt makes it more likely that $(r - g)$ will increase, amplifying the effect of adverse shocks in $(r - g)$ and potentially triggering a *snowball effect* (Lian et al. 2020).

A long-term perspective of safe interest rates implies that public debt issuance comes with a low fiscal cost. However, the presence of sovereign risk may justify the implementation of *budget adjustment mechanisms*. As stressed by Blanchard (2023), if the use of quantitative rules is unavoidable due to political constraints, the decision should rest on a rule that adjusts the primary budget balance to changes in debt service.

The European experience suggests that *sovereign risk* and *endogeneities* between *deficits* and GDP *growth* must be considered together when designing *fiscal policies*. Our dynamic model explores these dimensions and tests whether this fiscal rule is effective in preserving debt sustainability in an environment made nonlinear by the continuous interactions between fiscal policy, economic growth and real interest rates. Thus, we extend its original role, which was to reduce the stochastic uncertainty of $(r - g)$ and provide new insights to the debate (Blanchard 2023). We believe this is an important achievement, especially if the proposal for a system based on DSA fails due to political friction and negotiations return to focus on mechanical rules.

6 Conclusions

The EU fiscal framework must be reformed. Before the Covid-19 pandemic impacted EU public finances, the effectiveness of fiscal rules had already been questioned. Shortcomings became evident after the crisis of 2008, especially those related to ambiguities, the pro-cyclicality of fiscal policies and the widespread decline in public investment. The EFB (2019) provided an extensive overview of these weaknesses.

Therefore, the Commission's economic governance review of February 5th, 2020, launched a debate on how to improve the Stability and Growth Pact (SGP). With the EU deficit rising from 0.6% of GDP in 2019 to about 8.5% in 2020 and debt ratios at all-time highs, the Commission's review and consultation are taking place in a new context with potentially far-reaching implications. Both, the Covid crisis and the Ukraine war halted the process of soft review, giving to the debate a whole new spin. The second external shock in two years led the EC to postpone the enforcement of its fiscal rules to 2024.[15] Economic disruptions and insecurities, once considered temporary, are now set to remain, as is the question of *how to deal with future economic crises*.

In this scenario, long-standing shortcomings of the EU fiscal framework came to the fore: non-observable short-term policy indicators such as the *structural budget balance* are surrounded by uncertainty; the responsibility for sustaining investment has temporarily been delegated to NGEU but will require national follow-ups; fiscal stabilization (subject to sustainability constraints) must be reassessed to leave room for fiscal policy and support aggregate demand in a context of low interest rate.

A reform of the fiscal rules should have *two main objectives*: (i) *ensure public debt sustainability* while giving Member States the necessary fiscal space for domestic macroeconomic stabilization; (ii) *protect desirable forms of spending*, including public investment and spending that promotes common European goals.

Due to the significant risk of an upturn in inflation, there are fears of an increase in nominal interest rates and a reversal of $(r - g)$ in the future and a potential *snowball effect* (Jordà et al. 2020; Mauro and Zhou 2021). If $(r - g)$ remains negative, the dynamics of public debt are less frightening. However, because of endogeneity and potential nonlinearities, a high debt ratio can make countries vulnerable to an increase in $(r - g)$, even in a low interest rates environment (Lian et al. 2020). This curbs over-optimism and provides reasons to control public debt with *deficit adjustment rules*.

Using our framework, we can describe a *wide range* of potential scenarios. Some of our equilibria are stable but so close to the edge of instability, or chaos, that negligible shocks in monetary and fiscal policies or behavioral parameters can drive the economy toward *default*.

We tested the effectiveness of a *primary balance adjustment rule* to *debt service* to preserve *debt sustainability*. Notably, we show that a rule designed along these lines has mainly two advantages: *on the one hand*, it reduces the equilibrium debt level; *on the other hand*, it reduces (and potentially eliminates) the instability of potential *equilibriums*. Finally, in the face of possible *chaotic dynamics* related to the emergence of significant *risk premiums*, the fiscal rule has a stabilizing effect, by increasing the number of situations in which the debt ratio converges to a stable equilibrium.

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[15] "Our economy is still far from normality. And this is why we concluded in favour of extending the general escape clause of the Stability and Growth Pact through 2023"—Paolo Gentiloni (European Commissioner for Economic and Monetary Affairs), Brussels, 23 May 2022. (https://ec.europa.eu/commission/presscorner/detail/en/speech_22_3269).

Data and Codes The E&F Chaos codes used to simulate the nonlinear model is available on request.

Declarations

Appendix: A1. Fixed Points and Local Stability Analysis

Equilibrium (or stationary) situations are obtained from (7) by setting $b_{t+1} = b_t = \overline{b}$ in the *first dynamic equation* and $r_{t+1} = r_t = \overline{r}$ in the *second one*. From the first equation we get:

$$r = \mathrm{r}_1(\mathrm{b}) = \frac{\overline{g} + \delta\overline{r}}{\delta + 1} - \frac{\mu(b\gamma - 1)}{b(\delta + 1)(\varepsilon - 1)} \tag{9}$$

And from the second equation:

$$r = \mathrm{r}_2(\mathrm{b}) = \left(\frac{\propto}{\beta} - arctg(b - \overline{b})\right)^{1/3} + \overline{r} \tag{10}$$

Equilibrium points are located at the intersections of these two curves, whose graphs are represented in Fig. 3a. A typical situation is characterized by the presence of three equilibrium points with $b > 0$, say e_1 (*lower stable node*), e_3 (*middle unstable saddle*) and e_3 (*upper stable node*) with $0 < e_1 < e_2 < e_3$ and $r_1 < r_2 < r_3$. However, cases with more than two equilibria as well as one or no equilibria may exist, depending on the values of the parameters.

The *local stability* of each equilibrium can be determined through the usual linearization procedure based on the Jacobian matrix of the map (7):

$$DT(b, r) = \begin{bmatrix} \frac{(\varepsilon-1)(\bar{g}-r+\gamma\mu-\delta r+\delta\bar{r})}{(b\varepsilon\gamma-1)^2} & \frac{b(\delta+1)(\varepsilon-1)}{b\varepsilon\gamma-1} \\ \frac{\alpha}{(b-\bar{b})^2+1} & -3\beta(r-\bar{r})^2 \end{bmatrix} \tag{11}$$

computed at the equilibrium point, and the localization in the complex plane of its eigenvalues. In our model an analytical computation of the coordinates of the equilibrium points is not possible in general, hence the eigenvalues can only be computed *numerically*. For example, for the set of parameters of Fig. 3 (in the main text), we get $e_1 = (0.3917, 0.0002647)$, $e_2 = (0.6004, 0.024712)$, and $e_3 = (2.6642, 0.06025)$, and the corresponding eigenvalues are real given by $z_1(e_1) = -0.08015$, $z_2(e_1) = -0.01105$, $z_1(e_2) = -0.05630$, $z_2(e_2) = 0.00566$, and $z_1(e_3) = -0.05117$, $z_2(e_3) = -0.00445$. Hence, e_1 and e_3 are *stable nodes* whereas e_2 is a *saddle point*, located along the boundary of the basin of attraction of e_1.

Properties of Equilibrium Curves $r_1(b)$ and $r_2(b)$

The point at which the curve $r_1(b)$ intersects the *x-axis* occurs at:

$$b = \frac{1}{\gamma - \frac{(\varepsilon-1)(\bar{g}+\delta\bar{r})}{\mu}} \tag{12}$$

The point at which the curve $r_2(b)$ intersects the *x-axis* occurs at:

$$b = \bar{b} - tan\left(\frac{\beta\bar{r}^3}{\alpha}\right) \tag{12}$$

The point at which the curve $r_2(b)$ intersects the *y-axis* occurs at:

$$r = \bar{r} + \frac{-\alpha^{\frac{1}{3}}atan(\bar{b})^{\frac{1}{3}}}{\beta^{\frac{1}{3}}} \tag{13}$$

The limit for $b \to \infty$ of $r_1(b)$ is:

$$\lim_{b\to\infty} r_1(b) = \frac{\bar{g}+\delta\bar{r}}{\delta+1} - \frac{\gamma\mu}{(\delta+1)(\varepsilon-1)} \tag{14}$$

The limit for $b \to 0$ of $r_1(b)$ is:

$$\lim_{b\to 0} r_1(b) = -\infty \tag{A8}$$

The limit for $b \to \infty$ of r$_2$(b) is:

$$\lim_{b \to \infty} r_2(b) = \bar{r} + \frac{\alpha^{\frac{1}{3}} \left(\frac{\pi}{2}\right)^{\frac{1}{3}}}{\beta^{\frac{1}{3}}} \qquad (15)$$

The limit for $b \to 0$ of r$_2$(b) is:

$$\lim_{b \to 0} r_2(b) = \bar{r} + \frac{\alpha^{\frac{1}{3}} \left(-\frac{\pi}{2}\right)^{\frac{1}{3}}}{\beta^{\frac{1}{3}}} \qquad (16)$$

With the set of parameters used in Fig. 3a, b: $(r = 0, b = 0.3902)$; $(r = 0, b = 0.3838)$; $(b = 0, r = -0.0080)$; $(b \to \infty, r \to 0.0706)$; $(b \to 0, r \to -\infty)$; $(b \to \infty, b \to 0.0648)$; $(b \to -\infty, r \to -0.0208)$. When ε (i.e., the sensitivity of *primary budget adjustments* to changes in *debt service*) is increased to 0.1, the point at which the curve r$_1$(b) intersects the *x-axis* becomes: $(r = 0, b = 0.4055)$, while the limit for $b \to \infty$ of r$_1$(b) becomes: $(b \to \infty, r \to 0.0747)$.

Additional Figures and Tables

See Table 4, Figs. 7, 8, 9.

Table 4 Model calibration and parameter value estimated in the literature

Parameter	Description	Value	Range	Sample	Literature
α	Real interest rate adjustment to variation in debt ratio	0.0005	0.0003–0.0005	EU	IMF (2023), Alcidi and Daniel (2018)
β	Real interest rate adjustment to deviations from the target	10	1–10	US/EU	Carlstrom and Fuerst (2016), Brand and Mazelis (2021)
$\overline{b}$	Benchmark value for public debt	0.06	0.06	EU	Maastricht Treaty
δ	Interest rate impact on GDP growth	0.1	0.028–0.1	17 advanced economies	Jordà et al. (2020)
ε	Budget deficit adjustment rule	0.01	0.01–0.1	/	Policy parameter
γ	Fiscal policy impact on long-term GDP growth	1.5	1.70–3.60	Panel of 177 countries	Geli and Moura (2023)
$\overline{g}$	Exogenous GDP growth rate	0.03	0.023–0.035	EU/EA	Historical observation (1995–2023)
μ	Exogenous budget deficit	0.03	0.029–0.03	EU/EA	Historical observation (1995–2023)
$\overline{r}$	Target real interest rate	0.02	0.02	EA	ECB target

(a): $b_0 = 0.60$; $r_0 = 0.015$. (b): $b_0 = 1.30$; $r_0 = 0.025$.
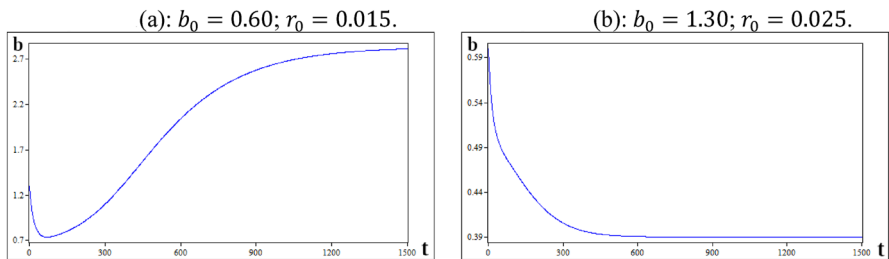

Fig. 7 Equilibrium debt ratios starting from *high* and *low* debt and interest rates. Same set of parameters of Fig. 3 (main text). **a** Shows the *time series* for public debt with the adjustment process starting from a low debt ratio (0.60) and a low real interest rate (0.015). **b** Shows the *time series* with the same adjustment process starting from a high debt ratio (1.30) and a high real interest rate (0.025). Source: Authors' own simulation
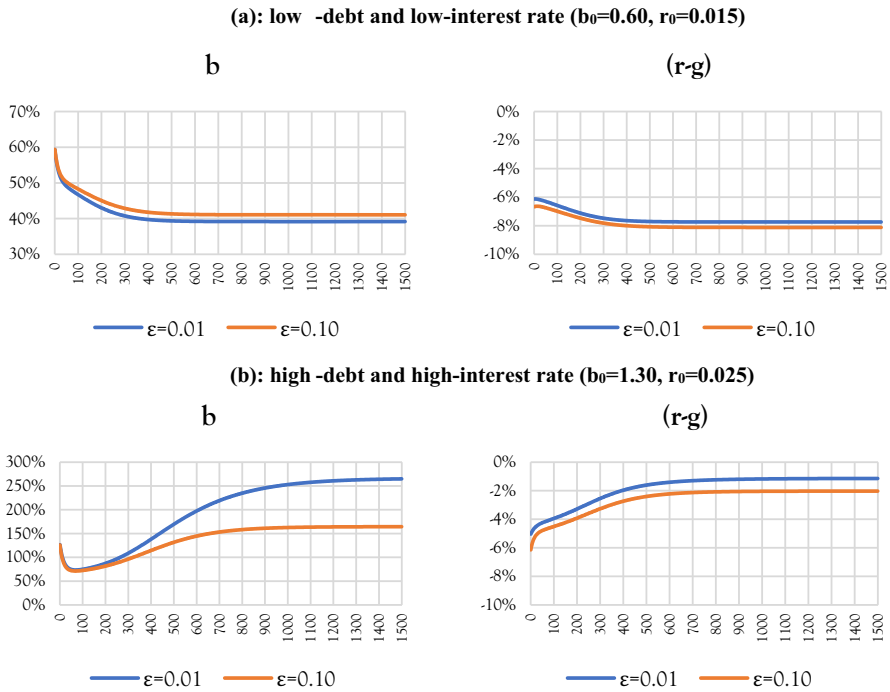
(a): low -debt and low-interest rate ($b_0=0.60$, $r_0=0.015$)

(b): high -debt and high-interest rate ($b_0=1.30$, $r_0=0.025$)

Fig. 8 The effects of an increase in ε on the equilibrium debt ratio and $(r - g)$. Same set of parameters of Fig. 3 (main text). An increase in ε (i.e., *primary balance adjustment rule to debt service*) from 0.01 to 0.1 effectively reduces the equilibrium debt ratio in the high-debt equilibrium (e_3). This is due to the impact on the interest rate, which now remains at a greater distance from the growth rate of the economy (*see* the decrease in r − g). The same impact is less significant on the interest rate in the low-debt equilibrium (e_1) (**a**). Source: Authors' own simulation
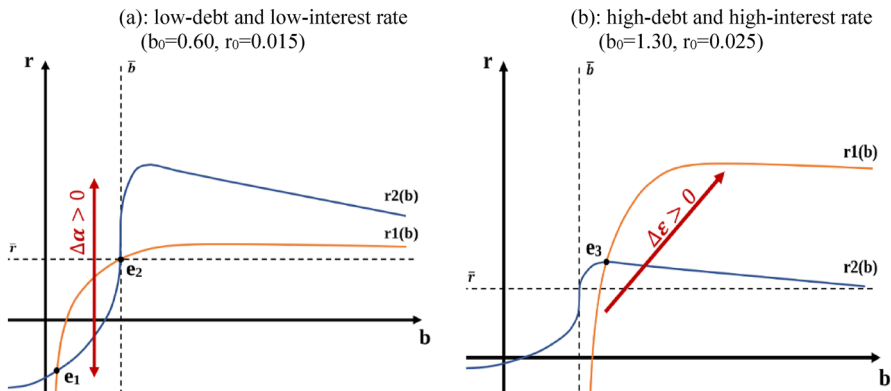
Fig. 9 Public debt and multiple equilibria (curve shift due to changes in α and ε). Same set of parameters of Fig. 3 (main text). An increase in α (i.e., *risk premium*) stretch the blue curve $r_2(b)$, moving the moving the equilibrium point e_1 downwards and the equilibrium point e_3 upwards (**a**). An increase in ε (i.e., *primary balance adjustment rule to debt service*) shifts the orange curve $r_1(b)$ to the right and upwards, increasing the equilibrium value e_1 and reducing e_3. Then, when a certain ε has been reached, e_1 and e_2 disappear and only one stable equilibrium (i.e., e_3) remains (**b**). Source: Authors' own simulation

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