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Dynamic Stability of Public Debt: Evidence from the Eurozone Countries

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Abstract: This paper investigates the dynamic stability of public debt and its solvency condition on the face of crises periods (1980-2021) in a sample of 11-euro area countries. The focus is on the feedback loop between dynamic stability of public debt and interest rates, discounted by the economic growth, in conjunction with budget deficits during tranquil and turbulent periods. Using the GMM panel dynamic model, the results show that dynamic stability was the case before the global financial crisis (GFC), while from GFC to pandemic, dynamic instability prevailed on the evolution of public debt. Moreover, dynamic instability exerted a highly persistent effect on the evolution of debt. Furthermore, panel threshold estimates show that dynamic instability of debt starts to violate the solvency condition when the borrowing cost is above 3.29%, becomes even stronger when it is above 4.39% and exerts even more pressure when the level of debt is greater than 91%. However, the debt sustainability condition reverses course when economic growth is higher than 3.4%. The main policy implication drawn from the results is that low interest rates can create a self-reinforcing loop of high debt, which is the issue for further research.

Keywords: debt dynamics; solvency; primary balance; panel thresholds

JEL Classification: G01; H6; H60; H61; H62; H63

1. Introduction

From the global financial crisis (GFC) to the COVID-19 pandemic the debt to GDP ratio has risen largely due to higher fiscal deficits, in response of emergency budgets undertaken by governments to limit the human and economic impact in both crisis periods (Bianchi et al., 2020). However, a country's public debt is considered sustainable if the government is able to meet all its current and future payment obligations without exceptional financial assistance or going into default. In addition, the elevated public debt has raised concerns about countries' capacity to reduce and stabilize it. In this sense, public debt is considered sustainable if the solvency condition holds, i.e., public debt could be repaid at some point in the future, and equals to the stock of past obligations (debt dynamics) plus the cost of debt and the primary balance.

From the theoretical point of view, Keynesian school recognizes that the impact of deficits in stress periods is temporary, and timely deficits have favorable effects on the economy. As a result, temporarily elevated debt drops to previous levels. However, neoclassical analysis argues that higher debt levels driven by the budget deficits created to face a crisis period (for example, when a crisis hits) are not temporary and austerity policy needs to be undertaken to restore to previous levels. Interestingly, recent studies claim that higher debt levels might be welfare enhancing if the growth rate is higher than the borrowing cost and economic growth is the main factor stabilizing the dynamics of debt, which is essential for the debt sustainability in the medium and long term (Debrun et al., 2019; Blanchard, 2019; Giannini and Oldani, 2022).

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In several euro countries the fiscal deficit fell to pre-crisis levels and economic growth was higher than interest rates despite a soaring public debt. The main reasons were the sizeable budget deficits and the low cost of borrowing which, over the past few years became more appealing due to extensive central bank's (the Fed) quantitative easing. Although the cost of borrowing may seem sustainable, the indirect cost of not reducing the public debt appears to be very high. The reason may be that higher debt may cause either a higher risk premium or changes in the multiplier effect of the stability of public debt. This second effect can be very important if debt levels are high.

Based on the above discussion, this study aims at investigating how dynamic stability of solvent affects the sustainability of public debt in view of crisis and regular periods. We use a sample of 11-euro area countries over the period of about 42 years starting from 1980. We contribute to the literature in four different ways. First, we examine the impact of dynamic stability/instability of debt on the development of public debt, not only in regular periods, but also in stress times. Second, we examine how the sustainability of public debt fares with interest rates affects, which in turn reflects the fear of default on public debt through high risk premium. Third, we provide new insights into the threshold effects above which dynamic stability of the debt to GDP ratio conditional on interest rates and vice versa, turns into instability. Fourth, as economic growth is considered as one of the main factors that can contribute to debt reduction, we examine threshold effects for annual growth to GDP, above which insolvency condition starts to disappear, thus making solvency condition to recover.

In this sense, we pay much more attention to the proper accounting of how the stability of debt (dynamics) affects debt development in conjunction with budget deficit before and after the GFC up to the COVID-19 pandemic. We also explore how the debt solvency condition, represented by interest rates, affects the debt's dynamic stability. Doing so, we provide new insights about the interest rates' threshold effects above which dynamic stability of debt turns to dynamic instability. We also examine the limits of debt dynamics above which the solvency is at risk, that is, when interest rate is growing faster than economic growth, implying higher sovereign risk premia. We further investigate the limits of economic growth above which government solvency is recovering. We perform a number of estimations of our models during a number of periods during which crises took place. Given that these periods entailed different economic and financial complexities, the insights derived from the findings will be of importance to all market agents. The results provide important implications for governments that may become insolvent and avoid to be forced to default knowing the levels of unsustainable debt dynamics. Also, government authorities can use the borderline (threshold) between a solvent and insolvent public debt and hence, avoid any signals of uncertainty to the markets.

The remainder of this paper is organized as follows. Section 2 provides a short review of the literature. Section 3 describes the theoretical model, the data sources and variable construction and the empirical model specification. Section 4 presents and discuss the estimated results and finally, section 5 summarizes the main findings.

2. Short Literature Review

Even though many factors go into assessing how much debt an economy can safety carry, a large number of studies in the empirical literature dealing with debt sustainability have focused on fiscal sustainability instead. Early studies for the Federal debt found that debt sustainability can be achieved in the sense of stationary primary deficit, satisfying an intertemporal budget constraint by raising the primary surplus, or equivalently, by reducing the budget deficit in the following years (Hamilton and Flavin, 1985; Trehan and Walsh, 1991; Bohn, 1995, 1998). Another strand of literature provided substantial evidence that non-stationarity of the debt cannot be rejected as government spending is growing faster than revenue (Kremers, 1988; Wilcox, 1989; Davig, 2005) . Nevertheless, the authors argued that the consequent rejections of stationarity do not invalidate propositions of Hamilton and Flavin (1985) and showed that the U.S. governments stabilized the ratio of Federal debt to GNP.

Contradictory conclusions are also drawn across studies where different samples of countries are examined, and sustainability of fiscal deficits had been receiving increasing attention, particularly for advanced economies and in the newly formed euro-area. The empirical results suggest that fiscal policy may not have been sustainable[1] in a sample of 18 OECD countries over the period 1970-2003 (Afonso, 2005), whereas fiscal sustainability is evidenced for euro-area countries, either by having a high debt to GDP ratio or violating the Maastricht treaty by permitting more than three percent of the deficit to GDP ratio (Greiner et al., 2007).

In crisis periods, governments attempt to boost household consumption through financial support for the unemployed, thus increasing public spending, which in turn increases government debt and the main approach for investigating debt sustainability is still fiscal sustainability (Challes et al., 2011). In line with Keynesian school, empirical evidence suggests that in a depressed economy any expansionary fiscal policy does not impose a future burden and the primary mechanism is the extra output because of the government purchases multiplier effects, whereas attempts to reduce the public debt via fiscal consolidation resulted in a high level of debt-to-GDP ratio through their negative impact on output (DeLong et al., 2012; Fatas and Summers, 2018).

However, in line with Neoclassical school, empirical evidence suggests that higher debt levels are driven by the budget deficits, mostly created by governments to face a crisis or stress periods. In turn, these fiscal shocks could deteriorate macroeconomic imbalances and chronic fiscal imbalances might lead to vicious austerity cycles, and only fiscal discipline is a means of achieving credible and shorter adjustments. Stability of public debt depends on a continuing tendency of fiscal policy to reduce the primary deficit (Neaime, 2015; Agnello et al., 2015; Dawood et al., 2017; Goedl and Zwick, 2018; Gaysset et al., 2019).

Another approach to examine the debt sustainability is fiscal solvency and the basic idea is to verify whether the present value of budget constraint would be pursued over the distant future. The findings suggest that a very high ratio of government debt to GDP affects the spread between government bond yields, increase the risk premium which subsequently affects the cost of financing for budget deficits, thus solvency condition is at risk (Ardagna et al., 2007; Cournede, 2010; Furceri and Mourougane, 2012). Besides, Ghosh et al. (2013) explored the debt limit above which the solvency condition is rejected, thus measuring the fiscal space, and showed that, as the debt is around 90-100 percent of GDP, the risk premium increases due to the higher probability of default, making higher interest rate expenses and, in turn, increasing the possibility of a permanently increasing debt-to-GDP ratio.

From a different aspect, a factor that can contribute to debt sustainability is economic growth. Many studies have reported that public spending volatility results in interest rate and output volatility, which in turn, undermine economic growth (Fatas and Mihov, 2003; Furceri, 2007; Afonso and Furceri, 2010; Afonso and Jalles, 2012). Gomez-Puig and Sosvilla- Rivero (2018) argue that public debt always has a negative impact on the long-run performance of a country's economy if public debt goes beyond 77% of GDP in a study within a sample of 101 countries (Grennes et al., 2010), and above 90% in a sample of 12 euro-area countries (Checherita-Westphal and Rother, 2012). Interestingly, empirical studies predict that the possibility of reducing debt through inflation is applicable in the medium and long term (Kwon et al., 2006; Aizenman and Marion, 2011; Akitoby et al., 2017; Giannini and Oldani, 2022)

Nevertheless, after the GFC, a prolonged period of low-interest rates in the EU has favored the stockpiling of debt because of the increased countries' capacity to borrow, but this does necessarily translate to ability to service higher debt levels. One question is whether debt-carrying capacities can sufficiently handle the elevated debt levels. Additional burdens of debt need to be more carefully managed. Also, controlling sustainability of fiscal deficits is insufficient if the countries are unable to roll over their debt, and the intertemporal solvency condition imposes mild restrictions on the paths of fiscal balances and debt levels that are consistent with a country being solvent. In our perspective,

1 A sustainable fiscal policy should ensure that the present value of debt approaches zero in infinity (Hamilton and Flavin, 1985; Afonso, 2005).

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the intertemporal solvency condition seems to be a weak criterion since only adjustments through taxes and spending have to be made to achieve debt sustainability. The solvency condition through fiscal adjustments is not supported, a change in policy or in relevant macroeconomic variables (growth, inflation, interest rate) must occur to stabilize the debt ratio and satisfy the solvency condition. If the debt-to-GDP-ratio increases over time, dynamic stability may become instability which, in turn, violates the solvency condition reflected by higher risk premium. This implies that dynamic instability is a stronger condition.

3. Methodology and Data

In this section, we lay out the theoretical motivation of the study and then the econometric specification. We also have a section on the data sources and variable construction. We begin with the theoretical model.

3.1. Theoretical model

Before proceeding to the empirical analysis, we first introduce the theoretical Keynesian model for the government debt, which is proposed by Schmitt-Groh´e and Uribe (2003) and Philippopoulos et al. (2016). The main macroeconomic policy instruments (fiscal and monetary) are linked through the government budget constraint as below:

$$T_t = G_t$$

where t subscript denotes the time, and T_t, G_t denote tax revenues and government spending respectively. Adding public debt

$$T_t + (B_t - B_{t-1}) = G_t + i_{t-1}B_{t-1}$$

where B_t is the end-of-period nominal public debt held by private agents, and i_{t-1} is the bonds' yield. Adding money revenues or sovereign revenues

$$T_t + (B_t - B_{t-1}) + (M_t - M_{t-1}) = G_t + i_{t-1}B_{t-1}$$

Dividing all terms by nominal output, $Y_t = P_t y_t$ the public debt-to-output ratio and the dynamics of public debt are given below:

$$\frac{B_t}{Y_t} = (1 + i_{t-1})\frac{Y_{t-1}}{Y_t}\frac{B_{t-1}}{Y_t - 1} + \frac{G_t}{Y_t} - \frac{T_t}{Y_t} - \frac{B_t}{Y_t} - \left[\frac{M_t}{Y_t} - \frac{Y_{t-1}}{Y_t}\frac{M_{t-1}}{Y_t - 1}\right]$$

or

$$b_t = \left[\frac{1 + i_{t-1}}{(1 + \gamma_t)(1 + \pi_t)}\right] b_{t-1} + g_t - t_t - \left[m_t - \frac{m_{t-1}}{(1 + \gamma_t)(1 + \pi_t)}\right] \quad (1)$$

where

$b_t = \frac{B_t}{Y_t}$ represents the public debt to GDP at period t,

$\gamma_t = \frac{Y_t - Y_{t-1}}{Y_{t-1}}$ and the Greek letter γ_t denotes growth rate of real output at period *t*,

$\pi_t = \frac{P_t - P_{t-1}}{P_{t-1-1}}$ and the Greek letter π denotes the inflation rate at period *t*, and,

$m_t - \frac{m_{t-1}}{(1+\gamma_t)(1+\pi_t)}$ is the money supply or so-called seigniorage at period *t*.

Other things equal dynamic stability of the debt-to-GDP ratio depends on the magnitude $\frac{1+i_{t-1}}{(1+\gamma_t)(1+\pi_t)}$ on the inherited debt in the equation (1) above. Dynamic instability means that the debt-to-GDP ratio increases over time. Also, fiscal solvency holds when it is believed that $g_t + \frac{g_{t+1}}{1+i_t} > t_t + \frac{t_{t+1}}{1+i_t}$, which says that the current level of debt should be equal to the expected present discounted value of future primary surpluses. If it is believed that $g_t + \frac{g_{t+1}}{1+i_t} > t_t + \frac{t_{t+1}}{1+i_t}$ the solvency condition is violated and we have insolvency

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3.2. Data sources and variable construction

This study employs annual data for a panel of 11-euro area countries over the period 1980–2021 with a total of 462 observations. The sample countries are Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal and Spain. Table 1 presents the data and its sources.

Table 1. List of variables.

variables	Description of variables	Sources
ggd	General government debt as a fraction of GDP(%)	IMF, Global Debt Database
ggdp	Annual percentage growth rate of GDP (%)	World Bank
cpi	Inflation rate (%)	World Bank
int	Long term interest rates (%)	International Monetary Fund
dyn	Dynamic instability as a fraction of GDP (%)	IMF Global debt database
pb	Primary balance as a fraction of GDP (%)	International Monetary Fund
ms	Growth rate of money supply (%)	European Data Warehouse
fdi	Net foreign direct investment as a fraction of GDP (%))	World Bank
open	Trade openness (exports + imports as a fraction of GDP (%))	European Data Warehouse

We construct the variable describing (measuring) debt dynamics as follows:

$$\left[\frac{1+int_{t-1}}{(1+ggdp_t)(1+cpi_t)}\right] ggd_{t-1}$$

where *int* is the long-term interest rates for government bonds, *ggdp* is the economic growth, *cpi* is the inflation rate and ggd_{t-1} is the level of public debt of the previous year.

3.3. Econometric model

Equation (2) below presents our panel model to investigate how dynamic instability affects public debt:

$$ggd_{it} = \alpha_1 + \beta_1' \boldsymbol{X}_{1it} + \gamma_1' \boldsymbol{Z}_{it} + u_{1it} \quad (2)$$

where the dependent variable *ggd* is the general government debt expressed as a percentage of *GDP* and subscripts *i* and *t* denote countries and time, respectively. Next, the matrix $\boldsymbol{X}_1$ includes the dynamic stability of public debt *(dyn)* and the primary balance *(pb)*. Matrix $\boldsymbol{Z}$ includes some macroeconomic variables – to be used as control variables - that are considered significant for the debt evolution, namely foreign direct investment *(fdi)* and trade openness *(open)*. Foreign direct investment and trade openness are both expected to be negatively associated with public debt, because of the endogenous relationship with economic growth (Li and Liu, 2005; Asteriou et al., 2023). Trade openness is the sum of exports and imports to GDP and constitutes an index for the degree of international trade. Next, in Eq.(3) we investigate the mechanisms linking the dynamic stability with public debt,

$$dyn_{it} = \alpha_2 + \beta_2' \boldsymbol{X}_{2it} + \gamma_2' \boldsymbol{Z}_{it} + u_{2it} \quad (3)$$

where the dependent variable is dynamic stability *(dyn)* and matrix $\boldsymbol{X}_2$ contains the lag of dependent variable and the primary balance *(pb)*. In the system of Eqs. (4) and (5) below, we examine the feedback of debt stability *(dyn)* on two main components of its coefficient-interest rates and economic growth. In this sense, we investigate how the solvency condition is affected by the dynamic stability.

$$int_{it} = \alpha_3 + \beta_3' \boldsymbol{X}_{3it} + \gamma_3' \boldsymbol{Z}_{it} + u_{3it} \quad (4)$$

$$ggdp_{it} = \alpha_4 + \beta_4' \boldsymbol{X}_{4it} + \gamma_4' \boldsymbol{Z}_{it} + u_{4it} \quad (5)$$

where the dependent variables are interest rates *(int)* and economic growth *(ggdp)*, while matrices $\boldsymbol{X}_3$ in Eq. (4) and $\boldsymbol{X}_4$ in Eq. (5), contain the lag of dependent variables, dynamic stability *(dyn)* and the

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primary balance *(pb)*.[2] In essence, we examine the nature and extent of the mutual interdependence between the two magnitudes.

Panel methodologies such as OLS and fixed effects estimators are consistent when *N* (no. of variables) is large but also when *T* (no. of periods) is large (Baltagi et al., 2016). However, a number of econometric problems plague such panel models such as the existence of bi-directional causality between variables, omitted variable bias, time-invariant country characteristics (fixed effects) - which may be correlated with the explanatory variables that can lead to endogeneity and misspecification - as well as the presence of autocorrelation (Bond and Windmeijer, 2002). Hence, the generalized method of moments (GMM) estimator was developed to overcome the above shortcomings as it controls for possible specification bias (Blundell and Bond, 1998) and it is well suited for datasets with small *T* and larger *N*. Following Holtz-Eakin et al. (1988), Arellano and Bond (1991) developed a GMM estimator that instruments the differenced variables with all their available lags in levels. A problem with this estimator is that lagged levels are poor instruments for first differences if the variables are close to behaving like a random walk. A system GMM is an augmented version developed by Blundell and Bond (1998) that overcomes this issue by employing both levels and differences as instruments while the assumption is that these differences are uncorrelated with the country specific effects.

Difference- and System-GMM are applied in one and two step variants. The two-step variants use a weighting matrix that makes two-step GMM asymptotically efficient. In this paper, we employ the system GMM estimator proposed by Roodman (2009) using a two- step approach and obtain robust standard errors with Windmeijer's (2005) finite sample correction. We provide results for the robustness and sensitivity of the instruments and coefficients and report Hansen's test of instrument validity and overidentifying restrictions, as well as the Arellano and Bond test for serial correlation.

3.4. Model specification for threshold effects

Further, we attempt to investigate possible threshold effects of dynamic stability and solvency conditions on public debt. For this reason, we examine the panel threshold effects of the interest rates above which dynamic stability is converted to instability or debt derailment. We also examine the solvency to insolvency transition mechanism. If the debt to GDP ratio increases, the impact of interest rates would increase because of the risk premium, thus violating the solvency condition. We apply the fixed-effect panel threshold model proposed by Hansen (1999). The empirical models are provided below

$$ggd_{it} = \mu_i + \beta'_{11}\boldsymbol{X}_{it} + \beta'_{12}\boldsymbol{int}(\boldsymbol{I})(\boldsymbol{dyn} \leq \boldsymbol{\gamma_1}) + \beta'_{13}\boldsymbol{int}(\boldsymbol{I})(\boldsymbol{\gamma_1} \leq \boldsymbol{dyn} \leq \boldsymbol{\gamma_2}) \\ +\beta'_{14}\boldsymbol{int}(\boldsymbol{I})(\boldsymbol{dyn} \geq \boldsymbol{\gamma_2}) + \varepsilon_{1it} \quad (6)$$

and

$$ggd_{it} = \eta_i + \beta'_{21}\boldsymbol{X}_{it} + \beta'_{22}\boldsymbol{dyn}(\boldsymbol{I})(\boldsymbol{int} \leq \boldsymbol{\zeta_1}) + \beta'_{23}\boldsymbol{dyn}(\boldsymbol{I})(\boldsymbol{\zeta_1} \leq \boldsymbol{int} \leq \boldsymbol{\zeta_2}) \\ +\beta'_{24}\boldsymbol{dyn}(\boldsymbol{I})(\boldsymbol{int} \geq \boldsymbol{\zeta_2}) + \varepsilon_{1it} \quad (7)$$

where ***ggd*** is the dependent variable, $\boldsymbol{\mu_i}$ and $\boldsymbol{\eta_i}$ are the vectors of the country-specific fixed effect, $\boldsymbol{X_{i,t}}$ is a matrix that includes the budget deficit variable and the control variables (that is, net foreign direct investment and trade openness) and $\boldsymbol{\epsilon_{1it}}$, $\boldsymbol{\epsilon_{2it}}$ are the error terms. In Eqs. 6 and 7, ***int*** is the variable used as the regime-dependent variable to split the sample into regimes and ***dyn*** is the threshold variable. Finally, $\boldsymbol{\gamma_s}$, $\boldsymbol{\zeta_s}$ are the unknown threshold parameters for the threshold variables of debt dynamics and interest rates, respectively. ***I*** is the indication function, which takes the value 1 if the argument in parenthesis is valid, and 0 otherwise. We also apply the fixed-effect panel threshold model (Eq. 8) to examine possible threshold effects above which economic growth can recover the solvency condition.

2 Growth of money supply was found insignificant and is omitted to avoid instrumentality problem.

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$$ggd_{it} = \nu_i + \delta_1' \boldsymbol{X}_{it} + \delta_2' \boldsymbol{dyn(I)}(\boldsymbol{ggdp} \leq \boldsymbol{\theta_1}) + \delta_3' \boldsymbol{dyn(I)}(\boldsymbol{\theta_1} \leq \boldsymbol{ggdp} \leq \boldsymbol{\theta_2}) + \delta_4' \boldsymbol{dyn(I)}(\boldsymbol{ggdp} \geq \boldsymbol{\theta_2}) + \varepsilon_{3it} \quad (8)$$

where $\boldsymbol{dyn}$ is the variable used as the regime-dependent variable, and economic growth, $\boldsymbol{ggdp}$, as threshold variable, while $\boldsymbol{\theta}_s$ are the unknown threshold parameters for the threshold variable economic growth. All panel threshold models are examined for a triple threshold, which divides the equations into three regimes with $\boldsymbol{\beta}_s$ and $\boldsymbol{\delta}_s$ coefficients.

4. Estimation results

4.1. System GMM panel estimation results

To investigate the impact of dynamic stability during several crisis periods, we conduct estimates with different samples along the time dimension. The results of the empirical model (2) are presented in Table 2. We employ six different ranges of time slots, thus including normal and stress times over the examined period 1981-2021. In version I of the model, we examine the period 1980-1990, where the savings and loan (1980) and Latin America sovereign debt (1982) crises occurred, as well as stock market crash (1987) and junk bonds (1989). In version II of the model, the period 1990-2000 is examined, where a massive interest rate crisis occurred in Mexico (1994), while in 1997-1998 and 1999-2000 the Asia crisis and *dotcom* bubble occurred, respectively. In versions III and IV of the models, two subperiods are examined, the tranquil period in Europe (2000-2007), where the newly euro currency was created, and the global financial crisis (GFC) (2007-2013), which is a period that includes the EU debt crisis (2012) as well. Finally, in version V of the model, a normal (tranquil) period is examined covering the post-GFC period up to COVID-19 health crisis (2012-2018), while version VI examines the stress time during pandemic.

The findings reveal that across all examined periods, debt dynamics has a significantly positive effect on public debt, while the impact of budget deficit is significantly negative. Both signs were expected, since higher levels of debt to service cause an increase in public debt, whereas lower levels of budget deficit lead to lower levels of public debt. Interestingly, the results indicate that the impact of dynamic stability is stronger compared to the effect of budget deficit on public debt, over the periods 2000-2007 (pre-GFC), 2012-2018 (post-GFC) and during the pandemic (2018-2021).

A general conclusion is that debt dynamics seems to prevail in regular periods rather than in stress times, while this is not the case for budget deficit, which has a stronger impact when the aforementioned stress events occurred. However, during the 2020 health crisis, the effects of both variables tended to be equivalent.

Regarding the foreign direct investment *(fdi)*, the significantly negative impact on debt is found before the GFC period, while in the post-GFC period the impact seems to be very weak. Additionally, international trade *(open)* seems to be the driver in the reduction of public debt after the crisis. However, this is not the case during the GFC, as openness is significantly positive.

Table 2. Panel estimation results. Dependent variable: Public debt.

	(I) 1980-1990	(II) 1990-2000	(III) 2000-2007	(IV) 2007-2012	(V) 2012-2018	(VI) 2018-2021
Δdyn	0.0233***	0.493***	0.787***	0.360***	0.498***	0.962***
	(5.56)	(8.83)	(13.31)	(8.36)	(4.85)	(7.98)
Δpb	-0.589***	-0.893***	-0.514***	-0.880***	-0.483**	-0.903***
	(-8.79)	(-4.88)	(-4.87)	(-8.44)	(-2.79)	(-8.09)
fdi	-0.372***	-0.0598***	-0.0366**	0.0149	-0.0871*	-0.0698
	(-11.49)	(-5.35)	(-2.47)	(0.34)	(-1.99)	(-0.55)
Δopen	-0.0253	-0.148**	-0.0228	0.222**	-0.208**	-0.150*
	(-1.32)	(-3.26)	(-0.77)	(2.70)	(-2.78)	(-1.93)
cons	3.231***	1.146***	0.266	2.000***	0.208	0.0333
	(18.79)	(8.51)	(1.59)	(5.23)	(0.53)	(0.07)

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N	109	110	88	55	66	33
AR(1)	0.080	0.118	0.132	0.107	0.133	0.133
AR(2)	0.383	0.119	0.253	0.314	0.822	0.157
Hansen	0.751	0.724	0.725	0.243	0.307	0.182
Nr of instruments	10	11	10	10	8	8

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Numbers in parentheses denote t-statistics. The letter d denotes the first difference operator used for the variables that were transformed to become stationary.

We further investigate the mechanisms for higher levels of debt dynamics and the results presented in Table 3 indicate that lower budget deficits increase the debt dynamics in the pre-GFC period, whereas in the after-GFC period up to the pandemic this is not the case, thus suggesting that austerity through lower budget deficit contributes to dynamic stability. In contrast, the findings suggest that before GFC foreign direct investment contributes to the dynamic stability of debt, while during and after the GFC up to pandemic it seems that this is not the case. Moreover, trade openness corroborates the above result not only in the pre-GFC period but also in stress times, indicates that international trade contributes to debt sustainability.

Table 3. Panel estimation results. Dependent variable: Dynamic stability.

	(I)	**(II)**	**(III)**	**(IV)**	**(V)**	**(VI)**
	1980-1990	**1990-2000**	**2000-2007**	**2007-2012**	**2012-2018**	**2018-2021**
L.Δdyn	0.00629	0.434***	0.399***	1.879***	0.464***	0.266***
	(0.85)	(4.97)	(7.49)	(8.07)	(7.18)	(5.18)
Δpb	0.146	0.0549	0.380***	0.257	-0.892**	-1.506***
	(1.32)	(0.24)	(3.46)	(0.77)	(-2.39)	(-9.57)
fdi	-0.274***	-0.128***	-0.0809***	0.306**	0.474***	0.130**
	(-4.45)	(-3.88)	(-7.88)	(2.65)	(4.38)	(3.08)
Δopen	-0.123	-0.297**	-0.203***	-1.846***	-0.631**	0.137***
	(-1.81)	(-2.69)	(-4.90)	(-4.22)	(-2.41)	(3.22)
_cons	2.929***	1.551***	0.697***	-1.711	-1.272**	-0.628
	(7.61)	(4.87)	(5.62)	(-1.61)	(-2.30)	(-1.76)
N	98	110	88	55	77	44
AR(1)	0.087	0.071	0.095	0.04	0.033	0.017
AR(2)	0.910	0.124	0.333	0.250	0.296	0.853
Hansen	0.283	0.535	0.317	0.110	0.131	0.515
Nr of instruments	10	10	10	10	8	10

Notes: See notes Table 2.

Next, we investigate the feedback of debt dynamics to borrowing cost, thus examining the relationship between dynamic instability and solvency condition-expressed by interest rates and the results are reported in Table 4. The findings show that dynamic instability was not a problem before GFC, while during the GFC and in the post-GFC periods, debt instability heavily affected the borrowing cost, thus violating the solvency condition. By contrast, this is not the case for the pandemic period.

Finally, in Table 5, we present the results from the feedback of debt dynamics on economic growth. The overall findings suggest that debt dynamics contributes to higher economic activity only in the early period between 1980-1990, while after 2000 this effect is converted to negative, indicating that higher levels of debt hinder economic performance.

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Table 4. Panel estimation results. Dependent variable: Yield.

	(I) 1980-1990	(II) 1990-2000	(III) 2000-2007	(IV) 2007-2012	(V) 2012-2018	(VI) 2018-2021
L.yield	0.911***	1.030***	0.610***	1.159***	0.586***	0.919***
	(8.87)	(33.41)	(6.78)	(8.81)	(47.34)	(4.50)
Δdyn	-0.00218	0.00319	-0.0819***	0.0862**	0.102***	-0.112**
	(-0.27)	(0.20)	(-4.74)	(2.35)	(7.53)	(-2.44)
Δpb	-0.133*	-0.0898	0.0561	0.153***	0.115***	-0.379***
	(-1.98)	(-1.27)	(1.05)	(3.23)	(3.50)	(-6.95)
fdi	-0.0368	0.0253**	-0.00302	-0.148**	0.0655***	-0.0205
	(-0.27)	(2.23)	(-0.27)	(-2.43)	(3.80)	(-0.28)
Δopen	-0.0562**	-0.138***	0.0230	-0.163***	-0.0768***	-0.00129
	(-2.58)	(-4.57)	(0.96)	(-4.54)	(-3.96)	(-0.06)
_cons	0.854	-0.180	0.510**	0.206	-0.245**	-1.078***
	(1.51)	(-1.11)	(2.38)	(0.59)	(-2.60)	(-7.28)
N	109	110	88	55	66	33
AR(1)	0.029	0.036	0.056	0.043	0.014	0.047
AR(2)	0.977	0.587	0.390	0.125	0.343	0.753
Hansen	0.753	0.456	0.156	0.358	0.617	0.616
Nr of instruments	10	10	10	10	10	10

Notes: See notes Table 2.

Table 5. Panel estimation results. Dependent variable: Growth.

	(I) 1980-1990	(II) 1990-2000	(III) 2000-2007	(IV) 2007-2012	(V) 2012-2018	(VI) 2018-2021
L.growth	0.730***	1.129***	0.407***	-0.231**	0.0613	-0.1000
	(9.22)	(4.05)	(5.55)	(-2.42)	(1.30)	(-1.39)
Δdyn	0.0278***	0.190	-0.239***	-0.265***	-0.206*	-0.283***
	(4.02)	(1.77)	(-14.71)	(-9.39)	(-1.89)	(-3.57)
Δpb	0.103	-0.133	0.226***	0.255***	0.116	0.722***
	(0.88)	(-0.47)	(7.58)	(7.80)	(0.63)	(12.33)
fdi	-0.0105	0.0776	-0.0635***	-0.0681	-0.00896	0.207***
	(-0.31)	(1.65)	(-6.10)	(-1.48)	(-0.12)	(3.79)
Δopen	0.0101	0.322***	0.146***	0.152	0.0672**	0.0365
	(0.63)	(6.40)	(10.24)	(1.72)	(2.36)	(1.32)
_cons	0.834***	-1.411	1.472***	1.827***	1.322***	1.608***
	(4.47)	(-1.42)	(4.27)	(8.41)	(4.30)	(3.40)
N	109	110	88	55	66	33
AR(1)	0.021	0.017	0.042	0.104	0.023	0.033
AR(2)	0.130	0.167	0.160	0.165	0.255	0.962
Hansen	0.505	0.891	0.164	0.463	0.963	0.457
Nr of instruments	10	10	10	10	10	10

Notes: See notes Table 2.

4.2. Panel threshold results

Tables 6–8 report the results of estimating equations 6, 7 and 8, respectively. In Table 6, we examine the effect of interest rates (solvency condition) on public debt conditional on debt dynamics (dynamic stability). The results suggest that the solvency is not a problem when the debt level is under 69.28% (as a fraction of GDP), where the effect of interest rates is negative and insignificant. This negative effect converts to significantly positive when the level of debt (dynamics) lies between 69.28% and 91.86% and the estimated coefficient turns from negative (-0.109) to positive (0.250). When

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debt dynamics exceeds the 91.86% threshold value, then we observe that the magnitude of the estimated coefficient on interest rates rises significantly, from 0.250 to 6.275, with a significantly positive effect at the 1% level of significance. This indicates that when debt level is around 92%, interest rates start to push debt to higher levels and this might be attributed to the violation of solvency condition which turns to insolvency.

In turn, we provide new insights within the estimated results from Table 7, where dynamic stability starts to push to higher levels of debt when borrowing cost is above 3.29%, and becomes even stronger when it is above 4.39%, thus leading to unsustainability of debt dynamics. The findings of threshold effects of public debt are in line with the existing literature (Checherita-Westphal and Rother, 2012), but this was the case of threshold effects of debt on economic growth. Our results, provide new insights regarding the mechanisms - solvency condition and dynamic instability - through which public debt rises. However, the results from Table 8 show that the solvency condition is reverses itslef when economic growth exceeds 3.4%.

Table 6. Regression estimates: Double threshold model for dynamic instability.

Regressors	coefficient	t-statistics	SE
Δpb	1.362***	(12.70)	(0.112)
ms	-0.126***	(-3.63)	(0.034)
fdi	-0.046*	(-1.74)	(0.026)
Δopen	-0.081*	(-1.72)	(0.047)
constant	0.933***	(2.39)	(0.394)
Δint(dyn≤ **69.28**)	-0.109	(-0.67)	(0.162)
Δint(**69.28** ≤dyn≤ **91.86**)	0.250**	(2.08)	(0.120)
Δint(**91.86** ≤ dyn)	6.275***	(8.68)	(0.722)

Notes:* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Dependent variable is public debt-to- GDP.

Table 7. Regression estimates: Double threshold model for interest rates.

Regressors	coefficient	t-statistics	SE
Δpb	0.964***	(5.83)	(0.100)
ms	-0.138***	(-2.96)	(0.032)
fdi	-0.049*	(-2.74)	(0.024)
Δopen	-0.152***	(0.67)	(0.045)
constant	1.144	(1.460)	(0.782)
Δdyn(int≤ **3.29**)	0.004	0.42)	(0.010)
Δdyn(**3.29** ≤int≤ **4.39**)	0.030*	(1.92)	(0.015)
Δdyn(**4.39** ≤ int)	0.152***	(5.04)	(0.030)
Notes: See notes Table 6.			

Table 8. Regression estimates: Double threshold model for economic growth.

Regressors	coefficient	t-statistics	SE
Δpb	0.586***	(5.83)	(0.100)
ms	-0.0966***	(-2.96)	(0.032)
fdi	-0.0686*	(-2.74)	(0.024)
Δopen	0.030	(0.67)	(0.045)
constant	3.518***	(4.89)	(0.719)
Δdyn(ggdp≤ **−0.70**)	0.054**	(5.99)	(0.009)
Δdyn(**−0.70** ≤ggdp≤ **3.40**)	-0.0026	(-0.24)	(0.810)
Δdyn(**3.40** ≤ ggdp)	-0.025***	(-5.94)	(0.011)
Notes: See notes Table 6.			

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5. Conclusions

In this study we used a Keynesian theoretical model proposed by Philippopoulos et al. (2016), to investigate how dynamic instability of public debt affect the solvency condition in view of the global financial crisis and pandemic. We use a sample of 11-euro area countries over the period 1980-2021. Employing GMM panel dynamic model the overall results show that dynamic stability was the case before the global financial crisis (GFC), thus not violating the solvency condition and only budget deficits significantly affected public debt evolution. However, after the global financial crisis up to the pandemic period as well as in both crisis periods, dynamic stability is converted to instability, which impacted the evolution of public debt.

Also, the findings suggest that after the global financial crisis dynamic instability shows a highly persistent effect on the evolution of debt and panel threshold estimates show that dynamic instability of debt start to violate the solvency condition when borrowing cost is above 3.29%, and becomes even stronger when it is above 4.39%. An additional finding is that dynamic instability exerts even more pressure when debt to GDP is greater than 91%. However, the solvency condition recovers when economic growth is higher than 3.4%.

The policy implications from these results are clear. First, low interest rates can create a self-reinforcing loop of high debt, which itself is a serious matter for public authorities when designing economic policies. Second, high debt levels cause stock and other financial instruments' prices to soar, thus additionally burdening an economy and derailing it. Finally, it is interesting to determine the crucial level of general government debt above which the debt becomes unsustainable posing serious threats to the economy's agents.

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