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RE-ANALYSIS OF THE EU PUBLIC DEBT CRISES WITH NARX

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ABSTRACT

This paper analyzes public debt in the Southern EU (Greece, Italy, Ireland, Portugal, and Spain) countries after the monetary union period. For this purpose, it adapts the public debt law of motion equation, which includes variables rolling out a country's competitiveness such as past public debt, GDP, primary balance, real exchange rate, real interest, and inflation, to Southern EU countries. The analysis is performed with the Non-linear Autoregressive Exogenous Artificial Neural Network, which is a dynamic and robust statistical method for the post-monetary union period consisting of quarterly data between 2005Q1 and 2021Q4. The analysis results show that the public debt in the relevant period in the Southern EU countries is robustly and statistically explained by the combined effect of the independent variables of the public debt law of motion equation, with a confidence rate of over 95%. This result implies that the public debt problem in Southern EU countries is associated with the competitiveness of these countries. In addition, the analysis goes beyond parametric analyzes that relate it to economic growth or a few variables in the estimation of public debt and uncovers the significance of inclusive variables and non-parametric analyzes included in the public debt law of motion equation in solving the problem.

Key Words: *EU Public Debt Crises, Southern EU Countries, NARX, Competitiveness Problems.*

JEL Codes: *C45, F35, F45, N14, N24.*

AB KAMU BORÇ KRİZİNİN NARX İLE YENİDEN ANALİZ EDİLMESİ

ÖZET

Bu makale parasal birlik döneminden sonra Güney AB (Yunanistan, İtalya, İrlanda, Portekiz ve İspanya) ülkelerinde kamu borcunu analiz etmektedir. Bu amaçla, geçmiş kamu borcu, GSYH, dış denge, reel döviz kuru, reel faiz ve enflasyon gibi bir ülkenin rekabet gücünü temsil eden değişkenleri içeren kamu borcu hareket denklemini Güney AB ülkelerine uyarlamaktadır. Analiz, 2005Q1-2021Q4 arasındaki çeyreklik verilerden oluşan parasal birlik dönemi sonrası için dinamik ve güçlü bir istatistiksel yöntem olan Non-linear Autoregressive Exogenous Yapay Sinir Ağı ile yapılmaktadır. Analiz sonuçları, Güney AB ülkelerinde ilgili dönemde kamu borcunun, kamu borcu hareket

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denkleminin bağımsız değişkenlerinin birlikte etkisi tarafından %95'in üzerinde bir güven oranı ile güçlü bir şekilde istatistiksel olarak açıklandığını göstermektedir. Bu sonuç, Güney AB ülkelerinde ortaya çıkan kamu borcu sorununun bu ülkelerin rekabet gücüyle ilişkili olduğunu imâ etmektedir. Ayrıca, analiz kamu borcunun tahmininde ekonomik büyüme veya birkaç değişken ile ilişkilendiren parametrik analizlerin ötesine geçerek problemin çözümünde kamu borcu hareket denkleminin içerdiği kapsayıcı değişkenlerin ve parametrik olmayan analizlerin önemini ortaya koymaktadır.

Anahtar Kelimeler: *AB Kamu Borcu Krizi, Güney AB Ülkeleri, NARX, Rekabet Gücü Sorunları.*

JEL Kodları: *C45, F35, F45, N14, N24.*

1. INTRODUCTION

The EU public debt crisis broke out in Greece in 2009, and then spread to all EU countries, destabilizing the Southern EU countries. It was suggested that the 2008 global financial crisis triggered the public debt crisis in the European Union (EU) (see Howarth and Quaglia, 2015). The Southern EU (also called GIIPS) (Greece, Ireland, Italy, Portugal, and Spain) countries, which were at the center of the crisis, defaulted. With the bailout packages, IMF and European Central Bank (ECB) rescued Southern EU countries which could not pay their public debts during the crisis (see Hall, 2017). The unsustainability of public debt in the Southern EU countries had an adverse effect on the confidence in the EU. Therefore, it remains important to investigate the root reasons that strengthen the effects of the crisis in Southern EU countries.

Competitiveness disparities among Northern and Southern EU countries feed macroeconomic imbalances and structural issues in EU economic integration (see Hall and Soskice, 2001; Dallago and Guglielmetti, 2011; Hall, 2012; Lane, 2012; Gros, 2012; Iversen et al., 2016; De Ville and Vermeiven, 2016; Frieden and Walter, 2017). Hall (2012) and De Ville and Vermeiven (2016) state that Southern EU countries, which manufacture relatively lower value-added goods and services, have fragile macro-economies compared to the stable macro-economics of the North that produces qualified goods and services. Competitiveness inequalities, which conflict with the convergence approach that forms the basis of the EU, enhance the risks for the sustainability of the EU.

This paper focuses on the question of whether the public debt law of motion equation can statistically explain public debt in Southern EU countries in the post-monetary union period. Analyzing this question in detail, the contribution of this paper is noted as follows: (i) The paper employs robust statistical methods, and dynamic non-parametric NARX Artificial Neural Networks, in exploring public debt in Southern EU countries. The followings are performed for the dynamic NARX analysis designed for time series analysis to create this contribution: (a) The NARX network is professionally structured and aligned with the public debt law of motion equation. (b) Similarly, parameters for NARX analysis are determined in accordance with the public debt law of motion equation and data set. (c) Levenberg-Marquardt's backpropagation algorithm, which employs quadratic derivatives and produces effective

results, is selected for the training algorithm. (d) Robustness control is performed and checked whether the test and validation regression results supported the training performance results. (ii) It analyzes the public debt in the Southern EU countries by employing the public debt law of motion equation adapted to these countries. (iii) The paper unfolds the significance of competitiveness variables in Southern EU countries in explaining public debt. (iv) It demonstrates that the competitiveness problems of Southern EU countries have a significant role in the EU public debt crisis.

The remainder of the paper proceeds as follows: Section 2 reviews studies investigating the causes of the EU public debt crisis. Section 3 examines studies that empirically analyze public debt. Section 4 consists of six chapters such as the public debt law of motion equation, the data and methodology, descriptive statistics, artificial neural networks, NARX, and results of the empirical analysis. Section 5 consists of the conclusion.

2. CAUSES OF THE 2011 PUBLIC DEBT CRISIS

The EU public debt crisis broke out in Greece in 2009, and then spread to all EU countries, destabilizing the Southern EU countries. Many studies have examined the root causes of the EU public debt crisis. In this section, these studies are analyzed. In the literature, the public debt crisis is a significant topic for many researchers to study and understand the factors behind the crisis. In one of them, Reinhart and Rogoff (2009) demonstrated the common features of failures in financial markets. They emphasized that austere shocks in developed market economies disseminate rapidly to the environment due to the increasing economic interdependence among countries. Similarly, Iversen and Soskice (2012) contend that the international interdependence of coordinated and liberal market economies provides a structural basis for erupting global imbalances.

The global financial crisis, which took place in the United States in 2008, is mentioned that triggered a public debt crisis in the Eurozone in 2011. After the asset markets exploded in the US, the debt burden of the European-based private finance companies distributing housing loans in the US market became unsustainable. These institutions held a significant portion of residential mortgage-backed assets in the United States (Dallago and Guglielmetti, 2011). In the EU, governments had to undertake these debt burdens. After this stage, the crisis turned into a public debt crisis in the Eurozone (Hall, 2012). The Euro crisis erupted when the Greek government revealed that the former Greek government had manipulated foreign debt for the membership of the EU in 2009. Southern EU countries with high public debt faced severe issues during the crisis period (Olzhas, 2020). In proportion to the severity of the crisis, the foreign borrowing resources of these countries contracted. Collignon (2012) stated that a demanding liquidity problem that destabilizes the banking system arose. Southern EU countries were subject to the reversal of large private capital flows, sometimes referred to as "sudden situations" (Merler and Pisani-Ferry, 2012). Unemployment among young people aged 15-24 rose to over 22% during the crisis period (European Parliament, 2014). The contraction in revenues in parallel

with the increase in public debt was among the net results observed in Southern EU countries. A single exception to these results occurred in post-Brexit Ireland (see Table 1). If Ireland sustains its growth performance and reduces its public debt in the long-term post-Brexit, this factor can strengthen those in Southern EU countries who support leaving the union. Therefore, solving the problems of countries with low competitiveness in EU integration is now much more significant for the EU.

Table 1. Public Debt and GDP in Southern EU countries (1990-2020).

Countries	Variables	1990	2000	2005	2008	2009	2010	2015	2016	2017	2018	2019	2020
Greece	GDP	97	131	246	**353**	328	**297**	195	192	200	212	205	189
	PD	73	105	107	**109**	127	**146**	179	183	182	189	184	213
Ireland	GDP	48	100	212	**276**	237	**223**	**292**	**299**	**337**	**386**	**398**	**418**
	PD	93	36	26	**42**	62	**86**	**77**	**74**	**67**	**62**	**57**	**59**
Italy	GDP	1169	1147	1859	**2408**	2198	**2138**	1836	1876	1961	2093	2005	1884
	PD	95	109	107	**106**	117	**119**	135	134	134	134	134	155
Portugal	GDP	79	119	197	**263**	244	**238**	199	206	221	242	239	231
	PD	56	50	67	**76**	88	**100**	131	131	126	121	116	131
Spain	GDP	536	599	1154	**1632**	1490	**1423**	1195	1232	1312	1422	1393	1278
	PD	41	58	42	**40**	53	**61**	99	99	98	97	95	117

Notes: PD is public debt and GDP (at current prices, billion dollars). PD is shown as a percentage of GDP.
Source: International Monetary Fund (World Economic Outlook Statistics).

Frieden and Walter (2017) describe the crisis as a balance of payments (BOP) crisis in the Euro area (see also Gros, 2012). They uncover that capital and goods are increasingly transferred from countries with current account surpluses to countries with current account deficits. The EU public debt crisis is intertwined with banking, financial and macroeconomic imbalances affecting the Euro area (Lane, 2012). Significant macroeconomic imbalances emerged in the Eurozone due to export-led current account surpluses in the North and debt-driven current account deficits in the South (Hall, 2017).

While the current account deficit in the 1990s was insignificant in the pre-Euro period, it reached 14.60% of GDP in Greece, 11.80% in Portugal, 6.2% in Ireland, 8.9% in Spain, and 1.9% in Italy in 2008. While the current account deficit problem continues in Greece, and slightly in Portugal and Spain, it has recently improved in Ireland and Italy (see Table 2).

Table 2. Current Account Balance of Southern EU Countries (1990-2020).

Countries	1990	2000	2005	2008	2009	2010	2015	2016	2017	2018	2019	2020
Northern EU Countries												
Germany	3,1	-1,8	4,7	**5,7**	**5,8**	**5,7**	8,6	8,5	7,8	10,8	10,8	6,9
Netherlands	2,5	1,7	7	**5**	**5,4**	**6,9**	6,3	8,1	10,8	10,8	9,4	7
Austria	0,7	-0,7	2,3	**4,5**	**2,6**	**2,9**	1,7	2,7	1,4	1,3	2,8	2,5
Denmark	1	2	4,2	**2,9**	**3,5**	**6,6**	8,2	7,8	8	7,3	8,8	8,2
Belgium	1,8	4	2	**-1**	**1,7**	**1,6**	1,4	0,6	0,7	-0,8	0,3	-0,2
Southern EU Countries												
Greece	-3,6	-6	-7,4	**-14,6**	**-11**	**-10**	-1,5	-2,4	-2,6	-3,6	-2,2	-7,4
Ireland	-0,8	0,6	-3,5	**-6,2**	**-4,7**	**-1,2**	4,4	-4,2	0,5	6	-11,4	4,6
Italy	-1,9	-0,3	-0,9	**-2,8**	**-1,9**	**-3,3**	1,4	2,6	2,6	2,5	3	3,6
Portugal	-0,2	-10,8	-9,6	**-11,8**	**-10,3**	**-10,3**	0,2	1,2	1,3	0,6	0,4	-1,2
Spain	-3,4	-4,3	-7,3	**-8,9**	**-4,1**	**-3,7**	2	3,2	2,8	1,9	2,1	0,7

Notes: Current account balance of GIIPS countries is shown as a percentage of GDP (at current prices).

Source: International Monetary Fund (World Economic Outlook Statistics).

Dallago and Guglielmetti (2011) list the primary reasons for the increase in public debt as follows: (i) Weak competitiveness, (ii) Stagnant exports, (iii) Internal political pressure, (iv) Bank bailout costs, and (v) The cost of incentive programs. Copelovitch et al. (2016) attribute the structural factors underlying the crisis and hindering the solution to fundamental factors such as labor mobility, asymmetric susceptibility to shocks, and the lack of adequate fiscal stabilizers. According to Collignon (2012), the public debt crisis was caused in part by uncorrected long-term structural differences in the EU (key economic developments such as growth and competitiveness) and in part by uncooperative behavior among key policymakers in the EU (see also Boltho and Carlin, 2013).

According to Chinn and Frieden (2012), the EU public debt crisis consists of at least two crucial weaknesses in the original EU integration project. (i) Application of the common currency and policy in countries, which are structurally different from each other. (ii) The EU integration strengthens the relationship of increasing trust in borrowing. The authors emphasized that the sense of trust created by the EU causes international financiers to see all member countries as a haven. In their study, the authors underline that this factor drives down real interest rates, so governments, businesses, and households borrow more without adequately grasping the risks. Lower real interest rates have resulted in lower pricing of risk and easier access to credit. This factor led to the destabilizing effects of demand and inflation in Southern EU countries (Chinn and Frieden, 2012; Obstfeld, 2013). Financing current account deficits with low-interest loans from Northern EU countries led to the accumulation of external debt in Southern EU countries.

The slow-growing financial institutions of the Northern EU sought high-yielding opportunities in the Southern EU. As a result of this orientation, capital started to flow from the Northern EU to the

Southern EU (Frieden and Walter, 2017). Due to relatively higher inflation, real interest rates were particularly low in Southern EU countries (Obstfeld, 2013). Low real interest rates offered Southern EU countries significant incentives for borrowing (Frieden and Walter, 2017). Most of the loans flowed into the South's expanding non-tradable housing markets and related construction sectors (Giavazzi and Spaventa, 2011; Lane and Pels, 2012; Obstfeld, 2013; Frankel, 2015). The diversion of resources to non-tradable areas limited future growth in aggregate output. Moreover, it narrowed the available trade-related resources for paying foreign debt (Obstfeld, 2013).

Frankel (2015) highlights three structurally different challenges to monetary unions. Firstly, asymmetry issues caused by the inability of members to devalue. Secondly, fiscal problem, inconsistency resulting from keeping fiscal policy at the national level, even though monetary policy moved to a Euro-wide level. Thirdly, the banking problem is that monetary policy moves to the Euro level, while banking supervision remains at the national level. Since the monetary union is not accompanied by a substantial banking and fiscal union, the Eurozone does not fit the "dollar union" design in key respects (see also Lane, 2012).

After the entry of the Southern EU countries into the monetary union, the financial confidence effect has a significant contribution to the increase in their debts (Hall, 2017). Debt-driven expansion in the protected sectors of Southern EU countries made them susceptible to the confidence crisis that erupted in 2010 (Blyth, 2013; Jones, 2016; Frieden and Walter, 2017; Hall, 2017). Greece was financing its budget and current account deficits with cheap loans. This comfort ended up in severe debts in the long term (Dallago and Guglielmetti, 2011).

The flaws in the Euro area's governance structure exacerbate the macroeconomic disintegration. Increasing inconsistencies are reflected in current account imbalances, differences in inflation, and price competitiveness (Olzhas, 2020). Lane (2012) emphasizes that governments do not want to alter their policies to withstand the accumulating systemic threats in the EU region. The structural and institutional features of the Northern EU facilitated the export-led growth strategy of coordinated market economies. Nordic countries continued to increase their external surpluses by suppressing domestic demand with balanced budgets and internal devaluation (see Table 2). On the other hand, Southern EU countries followed a relatively expansionary fiscal policy aimed at the growth of domestic demand (Hall, 2012).

Thanks to their organized manufacturing, many of the Northern EU's coordinated economies are experts at producing high-value goods (De Ville and Vermeiven, 2016). Greece, Ireland, Spain, Portugal, and Italy lacked the institutional capacity for the coordinated skill-building and incremental innovation needed for high-performance export-led growth. At the root of the crisis is the fact that the Northern (specialized manufacturing) and Southern (tourism-based countries) countries have different equipment and competitive power in an advanced liberal system that causes external imbalances (see Hall, 2012).

While the exports of the Southern EU countries to the Northern EU grew slowly, their imports from the North increased rapidly (Hall, 2017). Southern EU countries, which are exposed to trade diversion effects caused by the loss of monetary character, lost a significant part of their manufacturing jobs in international markets to East Asian countries (Chinn and Frieden, 2012). This factor limits the long-term expansion in the incomes of Southern EU nations. Incrementing demand in the South increased inflation and adversely affected the competitiveness of these countries, while low-interest rates fueled asset booms, particularly in countries such as Spain and Ireland. Moreover, high inflation figures further reduced the real cost of borrowing in the South (Hall, 2012).

Dallago and Guglielmetti (2011) unfolded that while household debts in the incomes of Southern EU countries reached an unsustainable level, the households of Northern EU countries, which constitute the core of the Eurozone, were in a more financially sound position during the crises. Chinn and Frieden (2012) reveal that crises bring more adverse effects to Southern EU countries. Between 1996 and 2008, Germany's export volume increased more than twice that of the rest of the Euro, and its domestic demand decreased by 1.5 times compared to the rest of the Eurozone (Overbeek, 2012). While labor costs contracted by 3.9% in Germany in the 1998-2007 period, labor costs in Spain augmented by 30-40% in the same period (Copelovitch et al., 2016).

Greece had a budget deficit of 13.60% and a public debt/GDP ratio of 115% in 2009 (Caminal, 2011). The IMF and EU bailed out defaulting Greece in exchange for promises of strict budgets, austerity, and economic reform (Hall, 2012). Similarly, in Portugal, the government took advantage of the lowest interest rates to finance the growing public deficits (Frieden and Walter, 2017). The Spanish government stepped in to nationalize or bail out the banks responsible for the borrowing process to finance the bailouts (Lane, 2012). Portugal and Spain took advantage of similar programs of the IMF and the EU and joined the bailout program with promises of austerity and reform (Hall, 2012). In addition to austerity and structural reforms, the EU and IMF programs were established to recapitalize the banking system. Moreover, as an interim institution, European Financial Stability Facility (EFSF) was established to issue bonds based on guarantees from member states to provide financing in any future crisis (Hall, 2017).

Southern EU countries managed to grow relatively quickly with the high demand till the crisis (see Table 1). Governments lost the exchange rate tool they used to balance the effects of inflation on competitiveness due to the currency union (Dallago and Guglielmetti, 2011; Lane, 2012; Chinn and Frieden, 2012; Overbeek, 2012; Wignall, 2012; Olzhas, 2020). After the Monetary Union (Euro), Southern EU countries started to encounter high current account deficits (Obstfeld, 2013). The imposition of monetary policy on countries with insufficient competitiveness led Southern EU countries to rely on tourism, other service sectors, and bailouts for national financing (Chinn and Frieden, 2012).

In Greece and Portugal, in contrast to Ireland and Spain, the primary driver of demand was a massive adverse fiscal balance, with public debt promoted on favorable terms (Obstfeld, 2013). However, the more capital flowed into Ireland and Spain, the faster they grew. As increased growth asset prices rose, it appeared more attractive to lenders, resulting in more capital flowing into Ireland and Spain (Frieden and Walter, 2017). With the credit boom stalling, the decline in construction was particularly worrying for Ireland and Spain. Abandoned projects and falling property prices led to austere potential losses for lenders based on too many properties (Hall, 2017).

Two countries, which are at the center of the current Euro crisis, are Ireland and Spain. Rising real estate prices and demand reinforced each other in a cycle (Obstfeld, 2013). The synchronization of rising inflation with falling real interest rates in parallel with falling savings and increasing investments supported asset booms in these countries. Increasing structural problems associated with many private sectors caused debt expansion in Spain and Ireland, particularly in the context of asset booms (Hall, 2017). Ireland's primary problem emerged in the housing and banking sectors. The interest rates set in Frankfurt are the main obstacle for Ireland to implement its monetary policy. Failure to adopt the monetary policy following local conditions in Ireland is a significant reason for housing and banking issues (Frankel, 2015).

3. EMPIRICAL STUDIES INVESTIGATING PUBLIC DEBT

Some studies mentioned the adverse effect of public debt on investments. For instance, Elmandorf and Mankiw (1999) emphasize that public debt crowds out private investments and adversely affects economic performance in the long run. Similarly, Modigliani (1961), Gale and Orszag (2003), Baldacci and Kumar (2010), and Calderon and Fuentes (2013) reveal that high public debt affects investments adversely by raising interest rates in the long run. A significant number of studies dealing with the determinants of public debt investigated the effect of public debt on economic growth. Burnside et al. (2001), Hemming et al. (2003), and Calderon and Fuentes (2013) state that a public debt crisis in a country can trigger a currency crisis by adversely affecting economic growth. Aghion and Kharroubi (2007), Woo (2009), and Calderon and Fuentes (2013) uncover that high public debt will cause huge volatility and low growth by reducing the ability to implement anti-cyclical fiscal policies.

In a study conducted for EU member states between 2000 and 2010, Misztal (2010) determines that a 1% increase in public debt causes a 3% decrease in GDP on average. Kumar and Woo (2010) examine the effect of high initial public debt on economic growth in the next period. By employing panel data analysis for 1970 and 2007, the authors find out that the initial public debt and the economic growth in the next period are adversely related in emerging market economies. Drine and Nabi (2010) employ the panel data covering the 1970-2005 time period for 27 developing countries, and they discover that the increase in public debt decrease production efficiency for 27 developing countries. In other words, the authors find out a negative relationship between public debt and production efficiency.

Calderon and Fuentes (2013) investigate the relationship between economic growth and public debt between 1970 and 2010 for 136 countries through the panel data analysis technique. According to the outcomes of the analysis, public debt has an adverse and powerful effect on growth. Afonso and Alves (2014) investigate the relationship between public debt and economic growth. They used the panel data analysis technique for 14 EU countries between 1970 and 2012. As a result of the analysis, the authors find out an adverse relationship between public debt and economic growth. The summary consequents of studies that associate public debt with multiple variables are as follows: Belguith and Omrane (2017) investigated the determinants of public debt for Tunisia using the Vector Error Correction Model (VECM) for 1986-2015. According to the outcomes of the analysis, while real interest rate, budget deficit, and trade openness increase public debt, inflation and investments decrease public debt. According to the overall result of the analysis, the budget deficit is the most significant determinant of public debt. In a 70-country analysis for 1970-2010, Ghulam and Derber (2018) unfold that US treasury bills and LIBOR (in US dollars) have significant effects on defaults by using the duration analysis method. According to the outcomes of the analysis, while political uncertainty, public debt ratio, and inflation increase the probability of default, export growth decreases the probability of default.

Pepkas (2018) empirically examines the relationship between economic growth (the independent variable) and investment, private and government consumption, trade openness, population growth, and public debt for the Greek economy, using the Autoregressive Distributed Lag (ARDL) cointegration technique. According to the outcomes of the analysis, while the effect of public debt on GDP growth is insignificant in the pre-2000 period, the author finds out that increasing public debt after 2000 slows the rate of economic growth. In an analysis of 10 EU countries, Chirwa and Odhiambo (2018) investigated the debt-reducing or debt-creating determinants of public debt using the ARDL panel data analysis technique for 1970-2015. According to the outcomes of the analysis, while economic growth reduces the public debt in the short run, real exchange rate, investment, and population growth decrease public debt in the long run.

Sadik-Zada and Gatto (2019) explore the primary drivers of public debt growth for 184 countries. The authors discover that oil abundance, economic growth rate, the share of mineral rent in total income, foreign borrowing interest payments, and being a developing country have a statistically significant effect on public debt growth. Burriel et al. (2020) search the risks in economies with high public debt through Dynamic Stochastic General Equilibrium (DSGE) model simulations. The net results observed for highly indebted economies are as follows: (i) They lose more output in the crisis. (ii) In the long run, they are subject to factors that adversely affect the potential growth. (iii) They have fewer tools for countercyclical fiscal policy. (iv) They are more affected by the spillover effects of the crisis.

4. EMPIRICAL ANALYSIS

4.1. The Public Debt Law of Motion Equation

The public debt law of motion equation, which includes public debt dynamics, is given in Equation (1) (see Croce and Ramon, 2003; IMF, 2013; Chirwa and Odhiambo, 2018):

$$pd_t = f(pd_{t-1}, gdp_t, r_t, pb_t, rer_t, ir_t) \quad (1)$$

The description of the variables is as follows: pd_{t-1} is past public debt, gdp_t is economic growth, r_t is real interest rate, pb_t is primary balance, rer_t is the real effective exchange rate index, ir_t is inflation rate. The public debt law of motion equation is assumed to be a function of past public debt, economic growth, real interest rate, primary balance, real exchange rate, and inflation (see Fischer, 1993; Bosworth and Collins, 2003; Chirwa and Odhiambo, 2016, 2017, 2018).

In this study, instead of the primary balance in the public debt law of motion equation, the current account balance (cab), instead of the real exchange rate, the real effective exchange rate index ($reer$), and instead of real interest rate, interest rate for public bond yields (r) are used. This adjustment is made because the real interest rate and exchange rate are common to all EU member states. In addition, since the current account balance is the most emphasized variable during the crisis period, it is included in the equation instead of the primary balance. In this study, the public debt law of motion equation for Southern EU countries is adapted as follows (see Equation 2):

$$pd_{it} = f(pd_{it-1}, gdp_{it}, r_{it}, cab_{it}, reer_{it}, ir_{it}) \quad (2)$$

The variables that form Equation (2) are as follows: The dependent variable pd_{it} is the public debt, pd_{it-1} is past public debt, gdp_{it} is gross domestic product (with current prices), cab_{it} is the current account balance, r_{it} is the interest rate for public bond yields, and ir_{it} is inflation calculated with consumer prices.

4.2. Data and Methodology

The analysis resulted in 340 observations using the quarterly data of the Southern EU member countries covering the period 2005Q1-2021Q4 after the monetary union. Sample countries consist of Southern EU members (Greece, Ireland, Italy, Portugal, and Spain). In this study, the data of Eurostat are employed for sample countries. No logarithmic transformation or normalization is applied to the series. The primary reason for selecting a non-parametric analysis is that (i) the public debt law of motion equation contains many independent variables, (ii) many independent variables are not normally distributed, and (iii) the variables show different stationarity specifications, (iv) model countries in EU economic integration have many similar policies and practices, particularly the common currency, therefore, there is a severe cross-sectional dependence problem for sample countries. Therefore, this paper employs pooled panel non-parametric NARX analysis for the estimation. Finally, the variables employed in the model are reported in Table 3.

Table 3. Dependent and Independent Variables

Short Definition	Definition of Variables	Sources of Data
	Dependent Variable	
PD	Public Debt (Percent of GDP)	Eurostat
	Independent Variables	
GDP	Gross domestic products, current prices (Billions of U.S. dollars)	Eurostat
CAB	Current account balance, (Percent of GDP)	Eurostat
R	Interest rate –euro convergence criterion for bond yields (%)	Eurostat
REER	Real effective exchange rate - (2015=100)	Eurostat
IR	Inflation rate, consumer prices (%)	Eurostat

4.3. Descriptive Statistics

The mean public debt level of Southern EU countries during the sample period corresponds to 108.53% of GDP. This statistic shows that Southern EU countries have high public debt ratios. In addition, the mean current account balance of Southern EU countries has a negative outlook during the sample period. The variation between the maximum and minimum values is highest in prices and current account balance. GDP, CAB, IR and REER variables do not show normal distribution according to the Jarque-Bera test. This is an important reference for choosing a non-parametric method (see Table 4).

Table 4. Descriptive Statistics for Southern EU Countries

Descriptive Statistics	PD	GDP	CAB	R	REER	IR
Mean	108.53	104.44	-2.74	4.07	102.96	0.35
Maximum	209.30	219.56	20.40	25.40	114.98	3.63
Minimum	23.60	71.88	-63.50	-0.25	94.14	-3.02
Std. Dev.	41.81	22.05	8.37	3.52	3.54	1.00
Skewness	-0.01	2.89	-2.05	2.56	0.40	0.08
Kurtosis	2.60	12.51	15.62	13.54	3.50	3.21
Jarque-Bera	2.20	1756.85	2497.01	1949.26	13.03	1.03
Probability	0.33	0.00	0.00	0.00	0.00	0.59
Observations	340	340	340	340	340	340

Note: Eurostat calculated the real effective exchange rate index (REER) as 100 in 2015 for EU members.

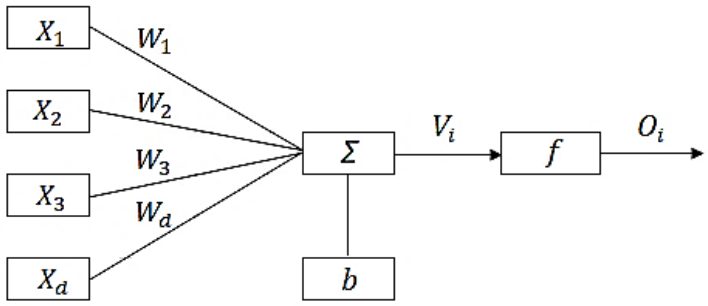
Source: Eurostat.

4.4. Artificial Neural Networks

ANN is a mathematical learning process that cyclically simulates the working system of the neural network mechanism of the human brain. Thanks to its learning ability, ANN(s) perform successfully in converging the minimum error. ANN(s) have flexible predictions, excellent generalization ability, trainable and adaptive content, and employ more general functional forms than advanced statistical methods. Zhang (2003) says that the evolution of ANN(s) is an art rather than a science.

ANN consists of nerves interconnected by directed connections. Each link has a numerical weight. In the neural network, bias is added to the activation function to set the actual threshold of the activation function (Mitrea et al, 2009).

Figure 1. Representation of the Activation Function



$$\text{Suppose } v_i = \sum_{j=1}^{d} w_{ij} x_j, \text{ and } o_i = y(v_i) \tag{3}$$

Here, y represents the activation function, (x_j) the input neuron, (o_i) the output of the neuron in the hidden layer, and (w) the weight matrix as shown in equation 4. The activation function realizes the learning function by adjusting the network weight matrix. The basic process responsible for training the network consists of three steps: (i) Forward transmission of input signals, (ii) Backpropagation of the error, and (iii) Adjusting the weights (Mitrea et al., 2009).

$$w = \begin{bmatrix} w_{11} & w_{12} & w_{13} \\ w_{21} & w_{22} & w_{23} \\ w_{m1} & w_{m2} & w_{m3} \end{bmatrix} \tag{4}$$

The primary task of ANN is to have an input-output function. Thus, the estimated residual is minimized.

$$\text{Suppose } (f): x_t \in R^k \rightarrow y_t \in R^1 \tag{5}$$

is a one-dimensional (y) output of a (k) dimensional vector of inputs

$$x_t^T = x_{1t}, x_{2t}, x_{3t} \dots \dots . x_{kt} \text{ at a given } (t) \text{ time} \tag{6}$$

$$\text{Let } (g): g(x_t, w_t): x_t \in R_{train}^k \rightarrow y_t \in R_{train}^1 \tag{7}$$

be a constraint of (f). In the first step, (w_t) values are assigned to converge the functional values of the unknown (g) as close to the known sample as possible. Let E(w) is a function defined as in equation 8 (Falat and Pancikova, 2015):

$$E(w_t)=\sum_{x_t y_t \in R^k_{train}} [g(x_t, w_t) - y_t] \quad (8)$$

Equation 8 denotes function (g)'s squares of the deviations from the expected values of the function (f). So (g) is a nonlinear function of (x_t). When a minimum is found, (g) is adapted for approximation of (f). In the second step, the error is calculated. Let (e_t) the error of the neuron, (d_1) the actual input value, and (y_t) be the output value of the network.

$$e_t \triangleq d_1 - y_t \quad (9)$$

Equation 9 shows the error rate of the neuron. In the third step, the weights are adjusted iteratively to reduce the error. The updated weights (w_{ij}) are calculated by correcting the weights with the learning rate (λ) in the range (0-1) to approach the minimum error.

$$\Delta w_{ij} = (\lambda) e_i x_j \quad (10)$$

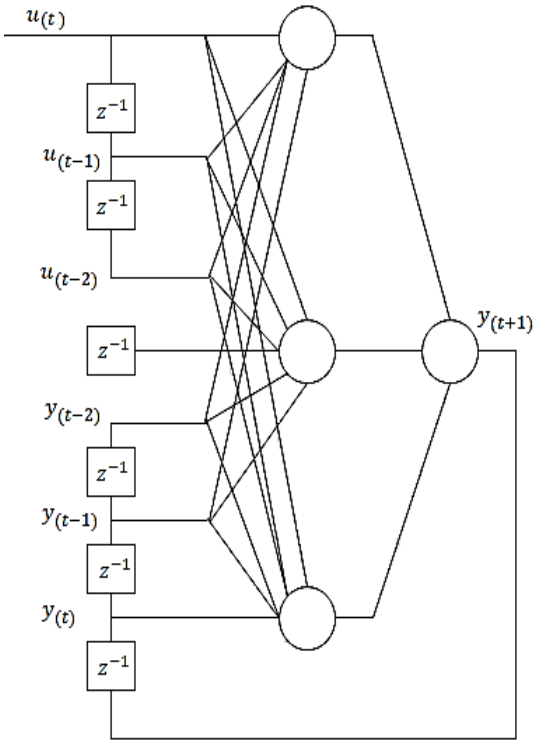
In equation 10, suppose that (x_j) is the input variable. If the learning rate (λ) represents a small value, the convergence to minimum error is getting stronger; on the contrary, if it represents a large value, the convergence to minimum error weakens.

Training or adaptation is performed on the training set. The validation set is applied to validate the training network. The convergence of training, validation, testing performances indicates that the ANN performs effective outcomes. On the other hand, while the training set reaches a high performance, "if the test and validation performances are insufficient", it is concluded that the network memorizes. In the case of network memorizing, the prediction can produce misleading outcomes.

4.5. Non-linear Autoregressive with External Input

NARX, a non-parametric model, is an effective analysis technique for time series predictions. NARX is a dynamic neural network (see Figure 2) used for input-output modeling with a forward and feedback multilayer (MLP) structure and a delay module (Tapped Delay Lines). As a dynamic model, it is considered an exogenous variable in NARX (X), which includes the past values of the dependent variable. (X) represents the influence of external factors on the solution of the problem considered in the model. The learning ability of NARX networks is stronger than other artificial neural networks. The main reason is that gradient descent in NARX produces excellent results compared to other networks. Therefore, the model converges faster and yields better results (Lin et al., 1996; Gao and Er, 2005; Diaconescu, 2008). According to Chaudhuri and Ghosh (2016), NARX is also very effective in approaching the local minimum in stationary and nonlinear time series predictions.

Figure 2. The Network Structure of NARX



Source: Chaudhuri and Ghosh, 2016.

Equation (11) denotes the mathematical representation of the NARX model. $p(t) \in R$ and $y(t) \in R$ represent input and output, and (dp) and (dy) represent embedded input and output memory, at time (t). (f) shows the function rolling out the dynamism of the system formed non-linearly (Lobo et al., 2014).

$$\bar{y} = f[p(t-1),..p(t-dp), y(t-1)..y(t-dy)] \quad (11)$$

$$(\text{in vector form } \rightarrow y(n+1) = f[y(n); p(n)])$$

4.6. Results of the Empirical Analysis

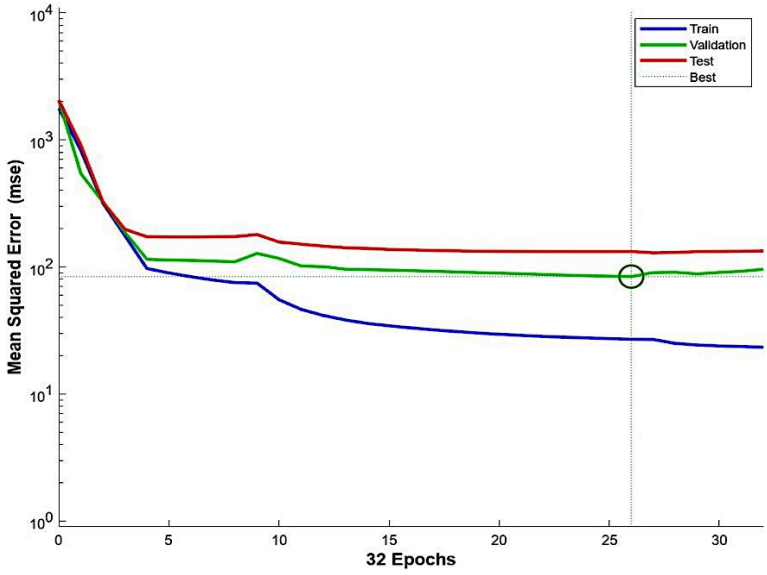
In this study, the application is made with the help of the MATLAB® R2022b program. The analysis obtains common results for all Southern EU countries (not specific for an individual country). The model consists of a non-parametric NARX artificial neural network technique pooled for panel data. The aim of the study is to uncover to what extent the independent variables (including the past dependent variable) can account for the dependent variable using the NARX technique.

When constructing an optimal NARX model, decisions must be made for the structural parameters that yield the most effective results. According to Yu et al. (2019), these decisions should be made for selecting the number of hidden layers, the number of neurons in the hidden layer, and the number of input layer delays. Selecting more than one hidden layer may complicate the problem and

result in ineffective solutions (see Masters, 1993). Therefore, this paper employs only one hidden layer. 70% of the data is allocated for training, 15% for testing, and the rest 15% for validation.

The number of neurons are chosen ten associated with the parameters and obtaining the minimum error values. In the selection of the lagged value of the dependent variable, one lag is selected to comply with the public debt law of motion equation (see Equation 1 and 2). According to Wilamowski and Chen (1999), the Levenberg-Marquardt (LM), which is derived from Steep Descent and Newton algorithms, employs quadratic derivatives and reveals fast and robust results for learning performance. Consequently, the Levenberg-Marquardt (LM) backpropagation algorithm is selected as the training algorithm. The sigmoid function is employed in the hidden layer while the linear function is employed in the output layer. Mean Error Square (MSE) values are checked for the training performance of the model. As a result of the analysis, the optimum result is obtained in the 32th iteration. The best validation performance is achieved in the 26th iteration (see Figure 3).

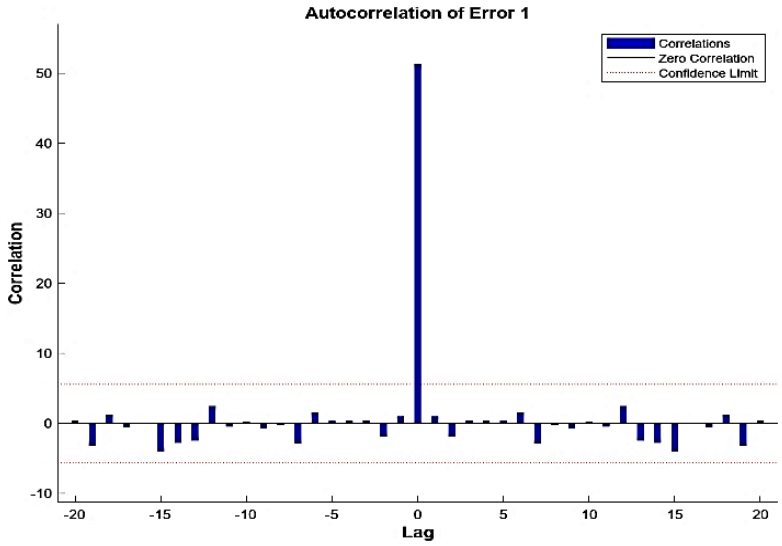
Figure 3. Best Validation Performance



Source: Obtained from MATLAB

Unlike other neural network techniques, NARX checks autocorrelation. There should be no autocorrelation problem while the MSE converges to the local minimum. Figure 4 denotes the autocorrelation results of the model. It can be seen that the blue bars are between the confidence limit. This result showes that all the correlations are under the confidence limit (see Figure 4).

Figure 4. Autocorrelation Check



Source: Obtained from MATLAB

The regression results of the model are shown in Table 5. According to the results in Table 5, the public debt law of motion equation statistically explains the public debt in Southern EU countries with a performance above 95%. In addition, test, training, and validation regression values are successfully converged with each other. This result demonstrates that the test and validation error squares as a robustness test approach the training error squares, thus the model does not memorize.

Table 5. Regression Results

Training and Robustness	Partitioned Data	Observations	R
Training	70	237	0.9926
Validation	15	51	0.9724
Test	15	51	0.9617

5. CONCLUSION

The analysis results uncover that the public debt in the post-monetary union period (2005Q1-2021Q4) including the EU public debt crisis in the Southern EU countries is accounted for by the combined effect of independent variables of the public debt law of motion equation, with a confidence rate of over 95%. The public debt law of motion equation has independent variables that are closely related to competitiveness. Competitiveness problems make Southern EU countries more vulnerable to crises. These consequences also are supported by Gros (2012), Collignon (2012), Hall (2012, 2017), Frieden and Walter (2017), and Olzhas (2020). The literature, which analyzes public debt, typically associates public debt with economic growth through parametric analysis. For instance, Misztal (2010), Kumar and Wo (2010), Calderon and Fuentes (2013), Afonso and Alves (2014), and Pegkas (2018) find

empirical evidence between public debt and economic growth. However, this article reveals the importance of the public debt law of motion equation in linking public debt. The public debt law of motion equation consists of important variables that are closely related to a country's competitiveness. Also, the equation is of a dynamic nature. Consequently, with these empirical findings, this paper contributes to the literature analyzing the determinants of public debt with a non-parametric analysis.

The proposals brought to the EU public debt crisis, which is difficult to find a solution due to the complexity of the problem, are debated in this section. The difficulty of the problem makes it important to discuss the solutions offered by the literature in detail. Collignon (2012) suggests a bond union for the EU based on portfolio laws. According to Collignon (2012), the risk components of EU bonds can be diminished by dividing these bonds into risky and risk-free groups. Hall (2012) states that the primary problem is to unfold how to resolve current account imbalances in the Eurozone. Hall (2012) claims that expansionary macroeconomic policies are not practical in the long run for the Northern EU, while continuous deflation will lead to significantly lower growth in the Southern EU. The root causes of the 2011 EU public debt crisis are still controversial. The complex nature of the EU public debt crisis, which complicates the political solution in terms of the economy, is among the significant factors that force this study (see also Chinn and Frieden, 2012; Frieden and Walter, 2017). Investigating the root causes of the 2011 EU public debt crisis is crucial for the structural solution. In this context, academic studies in this field should be strengthened. Presenting new ideas or strengthening the existing proposals can be beneficial for the political economy of the EU to roll out new ideas or enhance existing proposals by establishing new nonlinear and robust statistical models. Lastly, studies that offer solutions to the EU public debt crisis are included in the study.

In one of them, Chinn and Frieden (2012) state that the EU economic policy should take painful measures with serious distributional effects for the Eurozone to resolve the crisis. The authors contend that the failure of some countries to advocate this solution since it is costly will hinder the resolution of the crisis. Obstfeld (2013) argues that while promoting resilience and growth in the Euro area, the Euro area should be redesigned to improve policy discipline. Obstfeld (2013) emphasizes the need for new institutions at the EMU level to achieve this objective. Olzhas (2020) contends that as an excessive solution, mixed market economies in the South EU should leave the Eurozone voluntarily. This factor will let these countries take advantage of the exchange rate to enhance their competitiveness. Even though such a choice is possible, it is not suitable for all member states, because high social and economic costs may arise in living standards (Hall, 2014; Iversen et al., 2016: Olzhas, 2020). Olzhas (2020) rolls out three recommendations as follows; (i) balanced fiscal consolidation in the short-term, (ii) focusing on centralization of banking in the medium term, and (iii) adhering to structural reforms in the long term.

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