Non-Performing Loans (PLs) in a Crisis Economy: Long-Run Equilibrium Analysis with a Real-Time VEC Model for Greece (2001-2015)

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ABSTRACT

As a result of domestic and international factors, the Greek economy faced a severe crisis which is directly comparable only to the Great Recession. In this context, a prominent victim of this situation was the country's banking system. This paper attempts to shed light on the determining factors of non-performing loans in the Greek banking sector. The analysis presents empirical evidence from the Greek economy, using aggregate data on a quarterly basis, in the time period 2001-2015, fully capturing the recent recession. In this work, we use a relevant econometric framework based on a real time Vector Autoregressive (VAR) - Vector Error Correction (VEC) model, which captures the dynamic interdependencies among the variables used. Consistent with international evidence, the empirical findings show that both macroeconomic and financial factors have a significant impact on non-performing loans in the country. Meanwhile, the deteriorating credit quality feeds back into the economy leading to a self-reinforcing negative loop.

Keywords: VAR, VEC, NPLs, Greece, Crisis, Macro-economy, Banking sector

JEL codes: C32, G21

1. Introduction

Until recently, Greece had the 22nd highest standard of living in the world (Economist, 2005) and, according to Eurostat (2009), Gross Domestic Product (GDP) per inhabitant stood at 95% of the EU average. OECD (2002) characterized the performance of the Greek economy since the early 1990s “remarkable”, stressing the prevalence of high growth rates ranking second after Ireland among OECD countries. According to OECD (2007), this performance was primarily due to financial liberalization, EMU membership, growing exports and the Olympic Games in 2004.

However, as a result of domestic and international factors its debt rose from 105% of GDP (2007) to 170% (2011). In 2013, the proportion of the population in Greece living under the poverty threshold was equal to 23.1%, which is a record value since the 1990s and significantly above the EU-27 average of 16.6% (ILO 2014). In brief, the Greek crisis has reached points that are directly comparable only to the Great Recession including an approximate -25% contraction of GDP in the period 2008-2013 and a very high unemployment rate at 27%, with youth unemployment at 60% approximately. Cut backs in real wages are equal to -30% approximately, followed by a dramatic rise in suicides.

In such turbulent environments, the banking sector and especially commercial banks face elevated credit risk caused by the decreased cash flows of their borrowers. The corporate borrowers may have been impacted by weak demand for their products, while the household borrowers may receive lower income payments because of wage cuts or because they have become unemployed. In addition, the incentives of borrowers to repay their mortgages may have weakened in the face of adverse house price developments, possibly leading them into a state of negative equity (i.e. the price of the property being lower than the corresponding mortgage).

Consequently, it is widely accepted that the quantity or percentage of non-performing loans[1] (NPLs) is often associated with bank failures and financial crises in both developing and developed countries, as banks may face losses which undermine their solvency (e.g. Sorge 2004). The exploration of the determining factors of NPLs ratio, which can be used as a proxy for“ex post” credit risk, is an issue of substantial importance for regulatory authorities concerned about financial stability, while it presents great interest as a research topic. Despite the fact that banks have developed sophisticated models for quantifying “ex ante” credit risk, empirical studies have shown that “ex post” credit risk, as reflected in the number of non-performing loans, is mainly affected: (1) by macroeconomic factors (GDP cycle, unemployment rate, etc) and (2) by financial/bank-specific factors (credit growth, etc), i.e. factors which go beyond the microeconomic modeling, at the level of the borrower, which is conducted by each bank.

The present study attempts to identify the determinants of non-performing loans in the Greek banking sector and, more broadly, their bi-directional dependence with the economy, using aggregate data and a real-time Vector Autoregressive (VAR) - Vector Error Correction (VEC) model. We employ a number of relevant econometric tests to identify the properties of the data, such as their order of integration, the causality from a number of potential determinants towards NPLs and their mutual equilibrium relations. The study spans the period 2001Q4-2015Q1. The period under investigation includes both the growth phase (which began in the mid-

[1]A non-performing loan is a loan that is in default or close to being in default. Many loans become non-performing after being in default for 90 days, but this can depend on the contract terms.

1990s) as well as the downturn, following the global financial crisis and the Greek debt crisis. Therefore, our study benefits from the examination of a through-the-cycle sample enhancing the reliability of our results. This is the first empirical study in the literature which investigates the determinants of non-performing loans in Greece using aggregate data.

The banking system of Greece represents a “clean” prototype case for the empirical investigation of the determinants of non-performing loans. Specifically, the banks in Greece operate within a liberalized institutional environment, in the context of an advanced and closed economy which was growing rapidly, until the outbreak of the crisis. Furthermore, banks follow a traditional business model involving mainly deposit-taking and loan-granting while their trading activities are relatively limited and the shadow banking sector is not developed. Finally, the value of the currency is stable due to the participation of Greece in the Eurozone.

The aforementioned features of the macroeconomic and banking environment ensure that there is no significant impact by additional complicating factors which may be present in other jurisdictions, such as banks being highly involved in trading or originate-to-distribute activities, or swings in international trade or exchange rates affecting the macroeconomic environment, or, finally, issues of financial underdevelopment impacting on the evolution of banks’ profitability.

The remainder of the study is organized as follows: Section 2 provides a comprehensive review of the empirical literature on non-performing loans. Section 3 analyzes the theoretical framework and the variables used; Section 4 sets out the econometric methodology used. Section 5 presents the results of our empirical analysis. Finally, section6 concludes.

2. **Background Literature**

2.1 On non-performing loans

Over the last few years, the literature that examines non-performing loans has expanded in line with the interest afforded to understanding the factors responsible for financial vulnerability. This situation may be attributed to the fact that the quantity of non-performing loans, as we have already mentioned, is often associated with bank failures and financial crises in both developing and developed countries. In this section, we review the existing literature so as to formulate a theoretical framework to investigate the determinants of non-performing loans in Greece.

Keeton and Morris (1987)examined the losses by 2,470 commercial banks in the United States (US) during 1979-85.Using NPLs net of charge-offs as the primary measure of loan losses, the authors show that local economic conditions along with the poor performance of certain sectors explain thevariation in loan losses recorded by the banks.Theauthors also report that commercial banks with greater risk appetite tend to record higher losses.

Sinkey and Greenwalt (1991)investigated the loan-lossexperience of large commercial banks in the US. The study employs a simple log-linear regression model and data of large commercial banks in the United States from 1984 to 1987.The authors find empirical evidencethat both microeconomicand macroeconomicfactors explain the loan-loss rateof these banks.More specifically, they find a significant positive relationship between the loan-loss rate and microeconomicfactors such as high interest rates, excessive lending, and volatile funds.Moreover, the authors report that depressed regional economic conditions also explain the loss-rate of the commercial banks.

Keeton (1999) uses data from 1982 to 1996 and a vector autoregressive model to analyze the impact of credit growth and loan delinquencies in the US. The author reports evidence of a strong relationship between credit growth and impaired assets. Specifically, the author shows that rapid credit growth, which was associated with lower credit standards, contributed to higher loan losses in certain states in the US.

Salas and Saurina (2002) use a dynamic model and a panel dataset covering the period 1985-1997 to investigate the determinants of problem loans of Spanish commercial and saving banks, and findthat real growth in GDP, rapid credit expansion, bank size, capital ratio and market power explain variation in NPLs.

Ahmed (2006) investigates the relationship between non-performing loans, macroeconomic factors and financial factors in the context of private commercial banks in Bangladesh.More specifically, the author examines how banks' non-performing loans are influenced by three major sets of factors, i.e. terms of credit, bank size induced risk preferences and macroeconomic shocks. The author shows that bank size and horizon of loan maturity have negative influence on non-performing loans.

Hu, Li and Chiu (2006) analyse the relationship between NPLs and ownership structure of commercial banks in Taiwan with a panel dataset covering the period 1996-1999. The study shows that banks with higher government ownership recorded lower non-performing loans. The authors also show that bank size is negatively related to NPLs while diversification may not be a determinant.

Boudriga, Taktak and Jellouli (2009), studied the determinants factors of NPLs and the impact of bankingsupervision over the period 2002-2006 for a sample of 59 countries. The authors found that stricter supervision appears to reduce the level of impaired loans. They also found an association between non-performing loans and bank-specific variables such as the ratio of total equity assets weighted by risk.

Empirical studies that investigate the determinants of non-performing loans in the Greek banking system are limited to the study of Louzis, Vouldis and Metaxas (2010), where the authors emphasize on the effects of bank-specific variables on NPLs. This study, examines the determinants of NPLs, in which case there is always the risk that endogeneity issues may affect the results. The authors use the method of panel data to examine the determinants of NPLs in the Greek banking sector, which does not take into consideration the increased dynamic interdependencies among the different variables. The results show that impaired loans are related to certain macroeconomic variables and to the quality of management.

Greenidge and Grosvenor (2010), attempted to utilise univariate Autoregressive Integrated Moving Average (ARIMA) models and multivariate Autoregressive Distributed Lag (ARDL) models to estimate the aggregate NPLs ratio of the banking sector, as well as the NPLs' ratio of the individual commercial banksin Barbados, for the period 1996-2008. Their empirical results support the view that macroeconomic factors such as growth in real GDP, the inflation rate and the Treasury bill rate have an impact on the level of NPLs. In addition, the bank specific variables, growth in total loans and relative market share, seem to have explanatory power over non-performing loans.

More recently, Makri, Tsaganos and Bellas (2011) attempted to identify, using an econometric model, the factors affecting the NPLs Rate of the banking systems of the Eurozone for the period 2000-2008. Looking at both macroeconomic variables (e.g. annual percentage growth rate of GDP, debt as % of GDP, unemployment rate) and microeconomic variables (e.g. loans to deposits ratio, return on assets, return on equity), they investigated whether and which of these significantly affect the NPLs' rate. Their findings reveal strong correlations between NPLs and various macroeconomic (public debt, unemployment rate, annual percentage growth rate of GDP) and bank-specific (capital adequacy ratio, rate of non-performing loans of the previous year and return on equity) factors.

2.2 On the Greek banking sector

The evolution of the banking sector in Greece always reflected wider macroeconomic developments in the Greek economy.[2] The '80s and early '90s was a period with a slowdown in most economic indicators when compared with the pre-1974 post World War II period (Alogoskoufis 1995). The policies during the '80s have been assessed negatively by some authors (e.g. Bosworth and Kollintzas 2001, Christodoulakis et al. 1996, Tsakalotos 1998), while the reduction in the degree of protection created a negative environment for existing firms (Giannitsis 1993). During that period, the Greek banking system was highly regulatedas regardsthe quantity and the direction of credit and the interest rates charged (OECD 1986). In fact, credit granting decisions by Greek banks were often based on "personal contacts and social pressure" (Tsakalotos 1991, quoted in Gibson and Tsakalotos 1992, p. 61).

However, the situation was gradually changing, also because of Greece's accession to the European Economic Community in 1981 as a full member. The change became apparent,especiallyduring the '90s when most European Union (E.U.) governments introduced reforms in their banking sectors given that the gradual lifting of regulative restrictions on credit markets gained international acceptance. In this context, Greece as a member of the E.U. could not ignore the Directives which dictated great changes in the directions of liberalization, and aimed at increasing efficiency and competitiveness. Hence, a total of sixteen commercial banks were incorporated within fifteen years (Kamberoglouet *al.* 2004). Furthermore, this period featured a wave of mergers and acquisitions driven by economies of scale and banks seeking to expand (Eichengreen and Gibson 2001), as well as by technological improvements (Panopoulou 2005). Finally, the general trend towards "less government" is considered by several authors (e.g. Gibson and Tsakalotos 1992) as being conducive to financial liberalization.

The decade starting in 2000 saw a continuation of this trend, following Greece's accession to the euro area in 2001 and the impetus for growth provided by the Olympic Games in 2004 followed by the imperative to comply with the standards set forth by Basel II (2007), such as the setting up of a national credit register bureau, and the new bankruptcy law enacted in 2007 (Louzis et *al.* 2012). Quick credit expansion characterized that period which raised the total amount of loans issued by the main financial institutions from 24% (in 1999, when the implementation into the Greek law of the EU banking directives was completed) to 80 percent of the GDP in 2008 (Mitsopoulos and Pelagidis, 2011).Dellas and Tavlas (2012) place credit growth in the Greek economy, after joining the EMU, in the context of a monetary union in which automatic adjustment mechanisms are lacking. This absence is linked to unrestrained credit growth which is decoupled from the existence of strong fundamentals.[3]

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[2] For a brief review of the Greek economy, see Michaelides et al. (2013).

[3]Vouldis (2015) analyzes credit developments during this period, decomposing developments of supply and demand.

The outburst of the recent global recession led to distress for the Greek banking sector.Binding fiscal constraints originating at the sovereign level transmitted also to the financial intermediaries,while the subsequent fiscal consolidation measures have worsened the cash flow streams of both households and corporates. In addition, prevalent uncertainty about the economic prospects is not conducive to economic expansion.In this context, since the beginning of the debt crisis in Greece, the number of non-performing loans has increased significantly. According to the Bank of Greece (BoG) data, Greek banks' *Overall NPLs Ratio*, in the 4th quarter of 2009, amounted to 7.7%, while in the 3rd quarter of 2013, it amounted to 31,2%. Greek banks proceeded to make loan arrangements aiming to facilitate borrowers and reduce the rate of formation of new non-performing loans. Meanwhile, banks have sought to augment collateral to cover loans that have already been granted in order to reduce losses and impose stricter criteria for granting new loans. Despite ongoing efforts, the large amount of non-performing loans probably constitutes - as of the time of writing – probably the biggest challenge that the Greek banking sector is facing. In addition, it is considered that the deteriorating credit quality feeds back into the economy leading to a self-reinforcing negative loop.

3. Theoretical Framework and Variables Selection

The main indices of macroeconomic activity such as GDP and Unemployment have been identified as primary determinants of NPLs in the theoretical literature of life-cycle consumption models. For example, Lawrence (1995) and Rinaldi and Sanchis Arellano (2006) formulate models in which lower income leads to higher default rates due to unemployment leading to decreased cash inflows for the borrower. In addition, in this study, we also investigate the business impact and therefore include the cyclical component of GDP, which allows us to distinguish the effects of booms and recessions on NPLs. The relationship between cyclical developments and the inability of economic agents to service their debts represents a recurrent theme in the endogenous financial instability literature (Reinhart and Rogoff 2009).

Inclusion of public debt as a variable affecting NPLs is guided by the empirical literature on the connection between banking crises and sovereign debt crises, e.g. Reinhart and Rogoff (2010). Specifically, it has been posited that banking crises and sovereign crises are closely connected, and in fact banking crises can either precede or be the result of a sovereign crisis. The latter was the case in Greece (Louzis et al. 2012).

Consequently, we investigate the influence of: (a) Gross Domestic Product's Cyclical component (GDP Cycle), (b) Public Debt (D) and (c) Unemployment (U) on the NPLs ratio, in order to capture the dominant economic conditions prevailing in Greece for the examined period and how they affected the NPLs ratio.

We also test for the impact of financial factors on NPLs. In this context, we use the following variables: (a) Foreign Direct Investments (FDI) in the European Union (FDI-EU15)[4] and (b) Domestic Credit provided by the Banking sector (DCB) on theNPLs' ratio.The use of FDI is motivated by the contention of policy makers and academics that foreign direct investments can have important positive effects on a

[4]EU-15: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and United Kingdom.

host country's *development effort*[5]. Consequently we would expect that increased FDI would lead to increased and sustained income flows, therefore increasing the possibility of validating existing debt contracts, and, consequently, would lead to lower NPL levels. Moreover, as regards the DCB, economic theory suggests that the growth phase of an economy is characterized by a relatively low number of NPLs, as both consumersandfirms face a sufficient stream of income and revenues to service their debts. On the contrary, during recessions, banks curtail the provision of credit both due to supply-side constraints (if banks' solvency has been affected by the recession) and demand-side effects (mainly lack of positive net present value projects to fund).

Literature review provides evidence that both aggregate and disaggregate (individual bank) data could beused for similar investigations. Nevertheless, according to Boudriga et al. (2009), aggregate data for the whole banking system of a country (in contrast to the examination of individual data for each bank) are preferable in the sense that the risk of non-representativeness of the sample is reduced. In addition, investigating the aggregate data provides a benchmark against which assumptions for individual banks can be compared. The latter feature is especially useful in the context of conducting (top-down and bottom-up) stress test exercises or analyzing individual banks, whereby long time series will most surely not be present. For these reasons, we chose to examine exclusively *aggregate data* in our research.

The data are quarterly, and cover the time period 2001Q4-2015Q1. The time period examined includes both a period of growth (which began in the mid-1990s) as well as the downturn, following the global financial crisis and the Greek debt crisis. The data are expressed in € billions, except for unemployment (U) and NPLs that are expressed as percentages (%). The sources of the data used are the Bank of Greece (BoG), the Organisation for Economic Co-operation and Development (OECD), the World Bank and Eurostat. Additionally, we made use of two dummy variables, namely the Greek crisis and the Global crisis, in order to avoid any structural instability due to the two crises that affected the Greek economy. Table 1 summarizes the data and the variables used.

Table 1: Summary of Data and Variables

Variables	Period	Data length/Source
NPLs, GDP, D, U, FDI-EU15, DCB	2001Q4-2015Q1	Quarterly/BoG, OECD, Eurostat, WorldBank

[5]In addition to the direct capital financing it supplies, FDI can be a source of valuable technology and know-how while fostering linkages with local firms, which can help jumpstart an economy (see among others: Blomstrom, Lipsey and Zejan 1994, De Mello 1997 and 1999, Dees 1998, Lipsey 2000, Reisen and Soto 2001 andNair-Reichert and Weinhold 2001).

4. **Methodology**

An overview of procedures and methodology to be implemented in this study is hereby presented.

4.1 Properties of the original time series and their cyclical components

As we have discussed, a main aim of this study is to investigate the relationship between business cycles and NPLs. This investigation presupposes the decomposition of the original GDP time series into a trend and a cyclical component. In this work, we regard business cycles as fluctuations around a trend i.e. "deviation cycles" (Lucas 1997). The business cycle component is regarded as the movement in the time series that exhibits periodicity within a certain range of time duration based on Arthur F. Burns and Wesley C. Mitchell (1946).

- *Business Cycles*

More specifically, we regard business cycles as fluctuations around a trend, in the spirit of the seminal contributions by Lucas (1977), Kydland, and Prescott (1990), Alesina et al. (2008) and others. Now, every time series can be decomposed into a cyclical component and a trend component:

$$c_t = y_t - g_t \mathbf{(1)}$$

where: c_t is the cyclical component of time series, y_t is the actual time series and g_t is the respective trend that the time series exhibits.

- *Filtering*

A popular and appropriate method for extracting the business cycle component is the Baxter-King (BK) filter (Baxter and King 1999) and a large number of studies have used it, as of yet (e.g. Stock and Watson 1999, Agresti and Mojon 2001, Benetti 2001, Massmann and Mitchell 2004). The BK filter is based on the idea of constructing a band-pass linear-filter that extracts a frequency range corresponding to the minimum and maximum frequency of the business cycle. The algorithm consists of constructing two low-pass filters. The first passes through the frequency range $[0, \omega_{max}]$, denoted $\bar{a}(L)$, where L is the lag operator, and the second through the range $[0, \omega_{min}]$, denoted $\underline{a}(L)$. Subtracting these two filters, the ideal frequency response is obtained and the de-trended time series is:

$$x_t^{BK} = [\bar{a} - \underline{a}]x_t \mathbf{(2)}$$

Consequently, in order to examine whether the BK filtered cyclical component of the time series could be considered as cycle, we first have to check whether it can be considered to be white noise. Therefore, we test, based on the the Ljung and Box (1978) test, whether the white noise hypothesis is rejected for the cyclical component.

- *Testing for white noise*

The Ljung and Box (1978) test (Q-Stat), tests the null hypothesis of white noise for a maximum lag length k:

$Q = n(n+2)\sum_{j=1}^{k}\frac{\widehat{p_j}^2}{n-1}$**(3)**

where n is the sample size, $\widehat{p_j}^2$ the sample AC at lag j, and h the number of lags being tested; for significance level a, the critical region for rejection of the hypothesis of randomness is$Q > x^2{}_{1-a,h}$ is the a-quantile of the chi-squared distribution with h degrees of freedom.

Next, we continue by testing for the existence of unit roots in the various time series.

- *Unit Root Test*

There are several formal tests for unit roots. Here, we apply the Phillips-Perron (PP) test, which can be viewed as a Dickey–Fuller (DF) statistics that has been made robust to serial correlation by using the Newey–West (1987) heteroskedasticity -and autocorrelation- consistent covariance matrix estimator. The main advantage of the PP tests over the DF tests is that the PP tests are robust to general forms of heteroskedasticity in the error term u_t. Another advantage is that no a-priori specification of the lag length for the test regression is required.The popular Phillips–Perron (1988) test involves fitting the model:

$Y_t = a + \rho Y_{t-1} + \varepsilon_t$**(4)**

where we may exclude the constant or include a trend term. There are two statistics,$Z_\rho$and Z_τ, calculated as:

$Z_\rho = T(\widehat{\rho_T} - 1) - \frac{1}{2}\frac{n^2\widehat{\sigma^2}}{s_T^2}(\widehat{\lambda_T^2} - \widehat{\gamma_{0,T}})$**(5)**

$Z_\tau = \sqrt{\frac{\widehat{\gamma_{0,T}}}{\widehat{\lambda_T^2}}}\frac{\widehat{\rho_T} - 1}{\widehat{\sigma}} - \frac{1}{2}(\widehat{\lambda_T^2} - \widehat{\gamma_{0,T}})\frac{1}{\widehat{\lambda_T^2}}\frac{T\widehat{\sigma}}{s_T}$**(6)**

where, $\gamma_{j,T} = \frac{1}{T}\sum_{t=j+1}^{T}\widehat{u_t}\widehat{u_{t-j}}$, $\widehat{\lambda_T^2} = \widehat{\gamma_{0,T}} + 2\sum_{j=1}^{q}(1 - \frac{j}{q+1})\gamma_{j,T}$ and $s_T^2 = \frac{1}{T-k}\sum_{t=1}^{T}\widehat{u_t}^2$

where: u_t is the OLS residual, k is the number of covariates in the regression, q is the number of Newey–West lags to use in calculating λ_T^2, and$\hat{\sigma}$ is the OLS s.e. error of$\hat{\rho}$.

Under the null hypothesis that $\rho = 0$, the PP statistics,$Z_\rho$and Z_τ,have the same asymptotic distributions as the Augmented Dickey–Fuller (ADF) t-statistic and normalized bias statistics.

- *Cointegration*

In case the variables that enter the model are I(1) i.e. stationary in first differences then we have to check for cointegration between them, since if cointegration is present then the Error Correction Terms have to be employed in the estimation. We employ the popular Johansen (1988) methodology that allows for more than one cointegrating relationship, in contrast to other tests. The methodology is based on the following equation:

$$\Delta y_t = m + \Pi y_{t-1} + \sum_{i=1}^{p-1} \Gamma_\iota \Delta y_{t-i} + e_p \quad \textbf{(7)}$$

$$\text{where: } \Pi = \sum_{\iota=1}^{p} A_i - I \; and \Gamma_i = - \sum_{j=i+1}^{p} A_p$$

The existence of cointegration depends upon the rank of the coefficient matrix Π which is tested through the likelihood ratio, namely the trace test described by the following formulas:

$$J_{trace} = -T \sum_{i=r+1}^{k} \log(1 - \lambda_i) \quad \textbf{(8)}$$

where: T is the sample size and λ_i is the largest canonical correlation.

The trace test tests the null hypothesis of $r<n$ cointegrating vectors and the critical values are found in Johansen and Juselius (1990). Also, having stationary I(0) variables in the system is not an issue, according to Johansen (1995), as long as all the time series are integrated of the same order.

The full-blown model is based on the VAR-VEC methodology, and is described below.

- *Vector Autoregressive (VAR) - Vector Error-Correction (VEC) models*

(a) Mathematical Representation

The Vector Autoregressive (VAR) model is a technique that can be used to characterize the joint dynamic behavior of a set of variables without imposing restrictions of the kind needed to identify underlying structural parameters.

In mathematical terms, any $nx1$ vector of stochastic process x_t can be decomposed into two (2) orthogonal components, namely one linearly predictable and one linearly regular (Wold 1954). More specifically, if we let $\mathcal{M}_t$ be the time information set, then according to Wold's Theorem (1954), the following decomposition holds:

$$\mathcal{M}_t = \mathcal{M}_{t-1} \oplus \varepsilon_t \quad \textbf{(9)}$$

where: $\mathcal{M}_{t-1}$ contains the time information at time $t-1$, and ε_t is the information at time t. The implicit assumption made is that $\mathcal{M}_{t-1}$ is orthogonal to ε_t, while $\oplus$ indicates direct summation, i.e. $\mathcal{M}_t = \{\mathcal{M}_{t-1} + \varepsilon_t, \mathcal{M}_{t-1} \in \mathcal{M}_{t-1}, \varepsilon_t \in \mathcal{E}_t\}$.

Based on the above representation, it is easy to check that since $\varepsilon_t \perp \mathcal{M}_{t-1}$, then $\varepsilon_t \perp \varepsilon_{t-1}$ which, in turn, implies that $\varepsilon_{t-j} \perp \varepsilon_{t-j'} \forall j' < j$.

Now, since the decomposition on $\mathcal{M}_t$ could be repeated iteratively backwards for each time t, then the following equality holds:

$$\mathcal{M}_t = \mathcal{M}_{t-1} \oplus \varepsilon_t = \cdots = \mathcal{M}_{-\infty} \oplus \sum_{k=1}^{\infty} \varepsilon_{t-k} \quad \textbf{(10)}$$

where $\mathcal{M}_{-\infty} = \cap_j \mathcal{M}_{t-j}$. Since x_t is known at time t, then without loss of generality we can write $x_t = E(x_t/\mathcal{M}_t)$ using the conditional expectation. This, combined with the orthogonality of ε_t, implies that the following equation holds:

$$x_t = E(x_t/\mathcal{M}_t) = E(x_t/(\mathcal{M}_{-\infty} \oplus \sum_{k=1}^{\infty} \varepsilon_{t-k})) = E(x_t/(\mathcal{M}_{-\infty}) + \sum_{k=1}^{\infty} E(x_t/\varepsilon_{t-k}) \quad \textbf{(11)}$$

If we make the assumption that we consider linear representations, which in turn implies that we substitute the expectations operator with a linear projection operator, the above equations can be written as follows:

$$x_t = a_t x_{-\infty} + \sum_{k=1}^{\infty} D_{k,t}\varepsilon_{t-k} \textbf{(12)}$$

Where $x_{-\infty} \in \mathcal{M}_{-\infty}$ and $\varepsilon_{t-k} \in \mathcal{E}_{t-k}$. Then, the sequence $\{\varepsilon_t\}_{t=0}^{\infty}$, which is defined as $\varepsilon_t = x_t - E(x_{t-1}/M_{t-1})$, is a white noise process, i.e. $E(\varepsilon_t) = 0$, $E(\varepsilon_t \varepsilon_{t-k}') = \Sigma_t$ if $k = 0$ and zero otherwise.

Finally, if we assume that $a_t = a$ and $D_{k,t} = D_k \forall t$, then we get the Vector Autoregressive Representation (VAR) for any nx1 vector of stochastic processes.

$$x_t = a x_{-\infty} + \sum_{k=1}^{\infty} D_k \varepsilon_{t-k} \textbf{(13)}$$

(b) Econometric Representation

The VAR model also lends itself to empirical estimation, based on some assumptions.

Assumption 1:The history of each variable affects its own and the other variables' current state.

Assumption 2: No variable simultaneously affects any other variable.

Assumption 3:The dynamic evolution among the variables in the model is linear.

A model that takes into account Assumptions 1-3 is a VAR, and can be written as follows to ease estimation:

$$X_t = \begin{pmatrix} x_{1,t} \\ \vdots \\ x_{n,t} \end{pmatrix}, c = \begin{pmatrix} c_1 \\ \vdots \\ c_n \end{pmatrix}, A_i = \begin{pmatrix} a_{11,i} & \cdots & a_{1n,i} \\ \vdots & \ddots & \vdots \\ a_{n1,i} & \cdots & a_{nn,i} \end{pmatrix}, \varepsilon_t = \begin{pmatrix} \varepsilon_{1,t} \\ \vdots \\ \varepsilon_{n,t} \end{pmatrix} \textbf{(14)}$$

or:

$$X_t = c + A_1 X_{t-1} + \cdots + A_p X_{t-p} + \varepsilon_t \textbf{(15)}$$

where: $c_i$are constants, $x_{i,t}$ are the so-called endogenous variables $i,a_{ij,k}$ indicates the effect of variable $j$on variable $i$with a lag of k, and $\varepsilon_{i,t}$ is the residual time series of variable i. Now, the order$p$ of the VAR model shows how long we are going back in time.

The residual's vector ε_t, is assumed to be white noise, meaning that each vector element has a zero mean and a time invariant positive definite covariance matrix. Also, there is no correlation across time, and no autocorrelation in each of the individual error terms. In matrix form, we have:

$$\widetilde{X_t} = \begin{pmatrix} X_t \\ X_{t-1} \\ \vdots \\ X_{t-p+1} \end{pmatrix}_{pnx1}, \tilde{C} = \begin{pmatrix} C \\ 0_{nx1} \\ \vdots \\ 0_{nx1} \end{pmatrix}_{pnx1}, \tilde{A} = \begin{pmatrix} A_1 & \cdots & A_{p-1} & A_p \\ I_{nxn} & \cdots & 0_{nxn} & 0_{nxn} \\ \vdots & \ddots & \vdots & \vdots \\ 0_{nxn} & \cdots & I_{nxn} & 0_{nxn} \end{pmatrix}_{pnxpn}, \tilde{\varepsilon}_t = \begin{pmatrix} \varepsilon_t \\ 0_{nxn} \\ \vdots \\ 0_{nxn} \end{pmatrix}_{pnx1} \textbf{(16)}$$

Where: 0_{nx1} and 0_{nxn} are an n-dimensional zero vector and an $n \times n$ zero matrix, respectively. In this way, we obtain a compact representation of the VAR model:

$$\widetilde{X_t} = \tilde{C} + \tilde{A}\widetilde{X_t} + \widetilde{\varepsilon_t} \quad \mathbf{(17)}$$

Actually, we can express the VAR (p) model compactly as follows:

$$Y = A^* Z + U \quad \mathbf{(18)}$$

where: $Y = [X_{p+1}, X_{p+2}, \ldots, X_N]$, $A^* = [\boldsymbol{C}, A_1, A_2, \ldots, A_p]$, or:

$$Z = \begin{pmatrix} 1 & 1 & \ldots & 1 \\ X_p & X_{p+1} & \ldots & X_{N-1} \\ \vdots & \vdots & & \vdots \\ X_1 & X_2 & \ldots & X_{N-p} \end{pmatrix}, U = \left(\varepsilon_{p+1}, \varepsilon_{p+2}, \ldots, \varepsilon_N\right) \quad \mathbf{(19)}$$

This format is compact and also lends itself to an Ordinary Least Squares (OLS) estimation, with a straightforward form for the numerical solution:

$$A^* = YZ^T(ZZ^T)^{-1} \quad \mathbf{(20)}$$

In case we need to model effects which are exogenous to the system, this can be done by incorporating $q>0$ exogenous variables, $z_1(t)$, ..., $z_q(t)$, into the model as follows:

$$X_t = A_1 X_{t-1} + \cdots + A_p X_{t-p} + \boldsymbol{c}_1 z_{1,t} + \cdots + \boldsymbol{c}_q z_{q,t} + \varepsilon_t \quad \mathbf{(21)}$$

where: $\boldsymbol{c}_j$ is the vector of size $n\times1$ ($j = 1, \ldots, q$).

In order to estimate the extended VAR (p) model, we need to augment the definition of A^* by including $\boldsymbol{c}_1$, ...,$\boldsymbol{c}_q$ to obtain the OLS estimates of Ai and $\boldsymbol{c}_j$.

Finally, when the variables of a VAR are cointegrated, we use a Vector Error-Correction (VEC) model, by incorporating the error correction terms in the VAR model. More precisely, a vector error correction (VEC) model is a restricted VAR that has cointegration restrictions built into the specification, so that it is designed for use with non-stationary series that are known to be cointegrated. The VEC specification restricts the long-run behavior of the endogenous variables to converge to their cointegrating relationships while allowing a wide range of short-run dynamics. The cointegration term is known as the error correction term (ECM) since the deviation from long-run equilibrium is corrected through a series of partial short-run adjustments.

Following the latest strand in the literature, we assess the results of the proposed VAR estimation using the so-called Generalized Impulse Response Functions (GIRFs), which provide results that are invariant of the ordering of the equations The GIRFs present how an unanticipated/unexpected shock in one of the variables affects the dynamic behaviour of the rest of the variables in the VAR-VEC system.

- ***Generalized Impulse Response Functions***

The GIRF are expressed as follows (Koop et *al.* 1996, Pesaran and Shin 1998):

$$I_{l\,(n)} = \sigma_{ll}{}^{-1/2} + B_n \Sigma e_l \forall n = 1, 2, \ldots \textbf{(21)}$$

where: $I_{l\,(n)}$ is the Impulse Response Function *n* periods after a positive standard error unit shock; σ_{ll} is the *l*-th row and *l*-th column element of the variance–covariance matrix of the lower Cholesky decomposition matrix of the error term which is assumed to be normally distributed; B is the coefficients' matrix when inversely expressing the VAR model as an equivalent MA process and e_l is the column vector of a unity matrix.

Finally, in order to assess the time profiles of the effects of the variables-specific shocks on the potential cointegrating relations in the VEC model presented earlier, we will make use of the respective Persistent Profiles (PP).

- ***Persistent Profiles***

The Persistent Profile (PP) of the j-th cointegrating relation, namely $b'_{ji} z_{it}$, in the i-th country $(j = 1, \ldots r_i)$ at an horizon $n \in \mathbb{N}$ with respect to a variable specific shock to the l-th element of y_t is given by the following expression:

$$PP\left(b'_{ji} z_{it};\ \varepsilon_{lt}, n\right) = \frac{b'_{ji} W_i B_n \Sigma_\varepsilon e_l}{\sqrt{\sigma_{ll}}}, n = 1, \ldots N \textbf{(22)}$$

where: σ_{ll} is the l-th diagonal element of Σ_ε; e_l is a selection vector with its elements corresponding to the l-th variable in y_t unity and zero elsewhere; and B_n is the coefficients' matrix, when inversely expressing the VAR model as an equivalent MA process for the n-th period.

- ***System Stability***

We also need to examine the stability of the model which will ensure that it does not exhibit explosive behaviours. Specifically, instability is avoided if each eigenvalue of **A*** has a modulus equal to or less than unity. Mathematically, the stability conditions are$|\lambda_i| < 1$ for $i = 1,2 \ldots$ in the real root case and in the complex root case, where: $\det(\mathbf{A}^* - \lambda_i I) = 0$ **(23)**

Finally, in order to determine the lag order of the VAR/VEC model employed, we will make use of the so-called Bayes Information criterion (BIC) introduced by Schwartz (1978), which is known to perform better than other tests in small samples.

- ***Lag Length Selection***

We make use of the BIC (Schwartz 1978) and the optimum lag length $\hat{\xi}$ is given by the following objective function:

$$\hat{\xi} = argmin_{\xi \le n}\{-2\frac{\ln(LL(\xi))}{n} + \xi\frac{\ln(n)}{n}\} \textbf{(24)}$$

where LL(ξ) is the log-likelihood function of a VAR(ξ) model, n is the number of observations, ξ is the number of lags.

5. Empirical Results

We begin our analysis by extracting, by means of BK filtering, the business cycle components of the Greek GDP, using a moving average specification of three (3) quarters, a minimum business cycle period of 6 quarters and a maximum 32 quarters (see e.g. Baum et al. 2006).

Next, we test if the GDP cyclical series is white noise. We use the Ljung and Box (1978) test (*Q*-stat).The results of the Ljung and Boxtest are presented in Table 2. We can see that there is no evidence of the GDP cycle series being white noise.

Table 2: LjungandBox Test Results

Variable	Lags	Q-stat	Prob> $\chi^2(4)$	White Noise
GDP cycle	4	142.81	**0.00**	NO

We proceed with determining the order of integration of the variables in the model. The results of the PP unit root test are presented in Table 3.

Table 3: Phillips-Perron Test Results

PP Unit Root Test Results (original variables)			PP Unit Root Test Results (first differences)		
Variables	**p-value**	**Stationarity**	**Variables**	**p-value**	**Stationarity**
NPLs	0.74	NO	NPLs	0.00	YES
GDP Cycle	0.00	YES	GDP Cycle	-	-
D	0.00	YES	D	-	-
U	0.41	NO	U	0.00	YES
FDI-EU15	0.00	YES	FDI-EU15	-	-
DCB	0.00	YES	DCB	-	-

Notes: When a variable is stationary in levels we use (-) in first differences.

PP statistics for GDP cycle, D, FDI-EU15 and DCB are all significant at the 10%, which leads to rejection of the null hypothesis that there is a unit root in the variables.Based on PP test, it is apparent that GDP cycle, D, FDI-EU15 and DCB are stationary in levels, which implies that GDP cycle, D, FDI-EU15 and DCB are I(0).

PP statistics for NPLs and U are all insignificant at the 5% level of significance, which leads to the non-rejection of the null hypothesis that there is a unit root in the variables. More specifically, NPL's and U were found to be I(1), i.e. stationary in first differences.

In the presence of I(1) variables in the model, we have to check for the potential existence of long-run relationships among them by means of a cointegration test. Before conducting the Johansen cointegration test we, use the BIC information criterion to select the number of lags to be included in the various specifications. The values of the BIC criterion are shown in Table 4.

Table 4: VAR Lag Order Selection

Endogenous Variables	Lags	BIC
NPLs, GDP Cycle, D, U, DCB	0	33.346
	1	33.083
	2	33.966
	3	32.630
	4	35.019

Based on the BIC criterion, we select three (3) lags. Next, we perform the Johansen cointegration test and Table 5 summarizes the results.

Table 5: Johansen Test for Cointegration

Maximum rank	Log Likelihood	Eigenvalue	Trace-statistic	Critical-value	Cointegration
0	-771.189	-	172.723	87.31	Yes
1	-732.893	0.770	51.123*	62.99	
2	-704.777	0.660	39.900	42.44	
3	-693.051	0.363	16.445	25.32	
4	-686.684	0.217	3.712	12.25	
5	-684.828	0.0689	-	-	

The results of the trace test, suggest the existence of one (1) cointegrating relationship in the VAR system[6]. The existence of this cointegrating relationship implies that the initial VAR model should be transformed into a VEC model through the inclusion of the appropriate error terms, in order to account for the long-run equilibrium relationships among the variables.

After having estimated the VEC model, we obtain the Generalized Impulse Response Functions (GIRFs). More specifically, we will base our analysis of Generalized Impulse Response Function (GIRFs) on the robust confidence bands (bootstrapped, 10.000 iterations), rather than the point estimates in order to avoid possible structural instabilities.

The GIRFs are computed for a shock equal to one standard deviation and for a horizon of 24 quarters, i.e. 2 years. The dynamic responses of NPLs to a shock in (a) GDP cycle (b) D (c) U and (d) DCB are presented in Fig. 1.

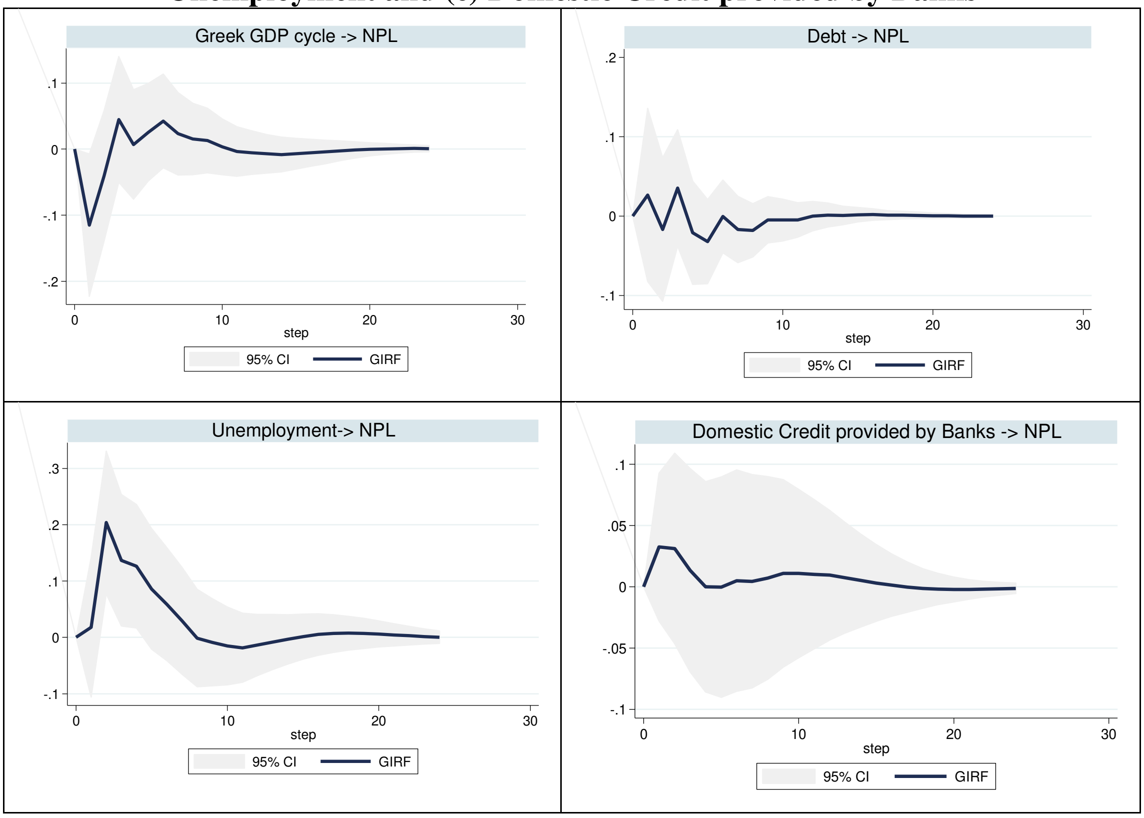
The response of NPLs to a shock in GDP Cycle is negative and statistically significant in the first two quarters, while in the long run the NPLs return back to their initial equilibrium position.The negative effect of GDP cycle on NPLs could be attributed to the fact that when the overall macroeconomic conditions deteriorate, and thus the recession (GDP cycle) deepens, then the NPL ratio also deteriorates.

[6] The results of the trace test for cointegration were the same with those obtained using the maximum eigenvalue statistic and are available upon request by the authors.

A shock in D affects positively the NPLs in the short run, while in the long run the NPLs return back to their initial equilibrium position. This result could be attributed to the fact that NPLs follows the rise in debt. Specifically, in the Greek case, a rise in debt led to a fall in economic activity, through a number of channels. For instance, there was primarily, the inability of the sovereign to service the public debt leading also to banks deleveraging in the face of solvency problems and economic uncertainty, market confidence affecting expectations in the market and, recessionary measures such as wage and investment cuts, and, subsequently NPLs rose significantly above their pre-crisis levels.

A shock in U affects positively and significantly the NPLs in the short run and for about 6 quarters. However, in the medium run, and especially after the 7^{th} quarter, the shock in U affects negatively the NPLs, while in the long run (after the 11^{th} quarter) the NPLs return back to their equilibrium position.

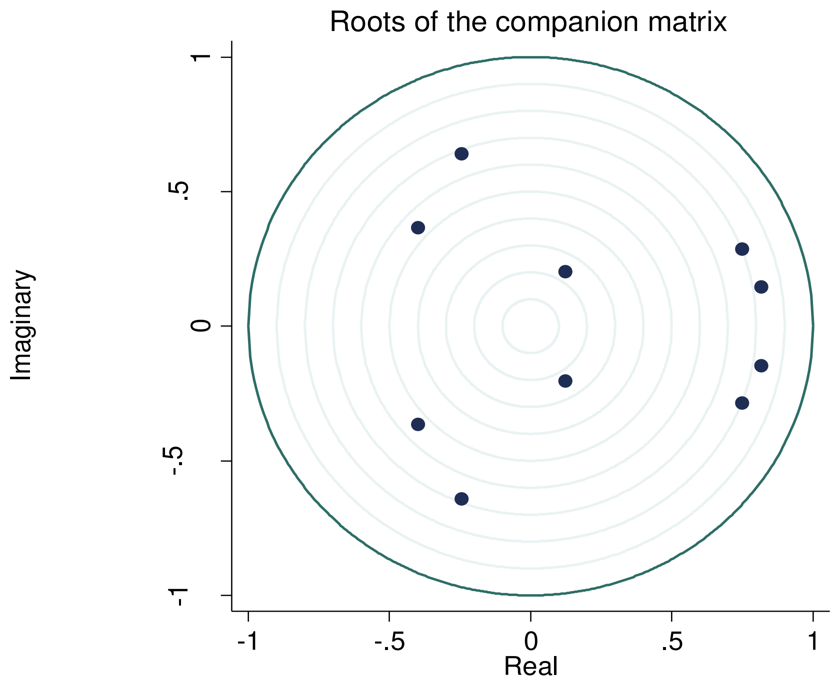
Figure 1: Response of NPLs to shocks: in (a) GDPcycle (b) Debt(c) Unemployment and (e) Domestic Credit provided by Banks



Finally, a shock in DCB affects positively the NPLs in the short run and for about 8 quarters. However, in the long run, the NPLs return back to their equilibrium position. The interpretation of this GIRF is that during the growth phase, a shock in credit supply would be associated with lower credit standards, and an increase of NPLs is observed.

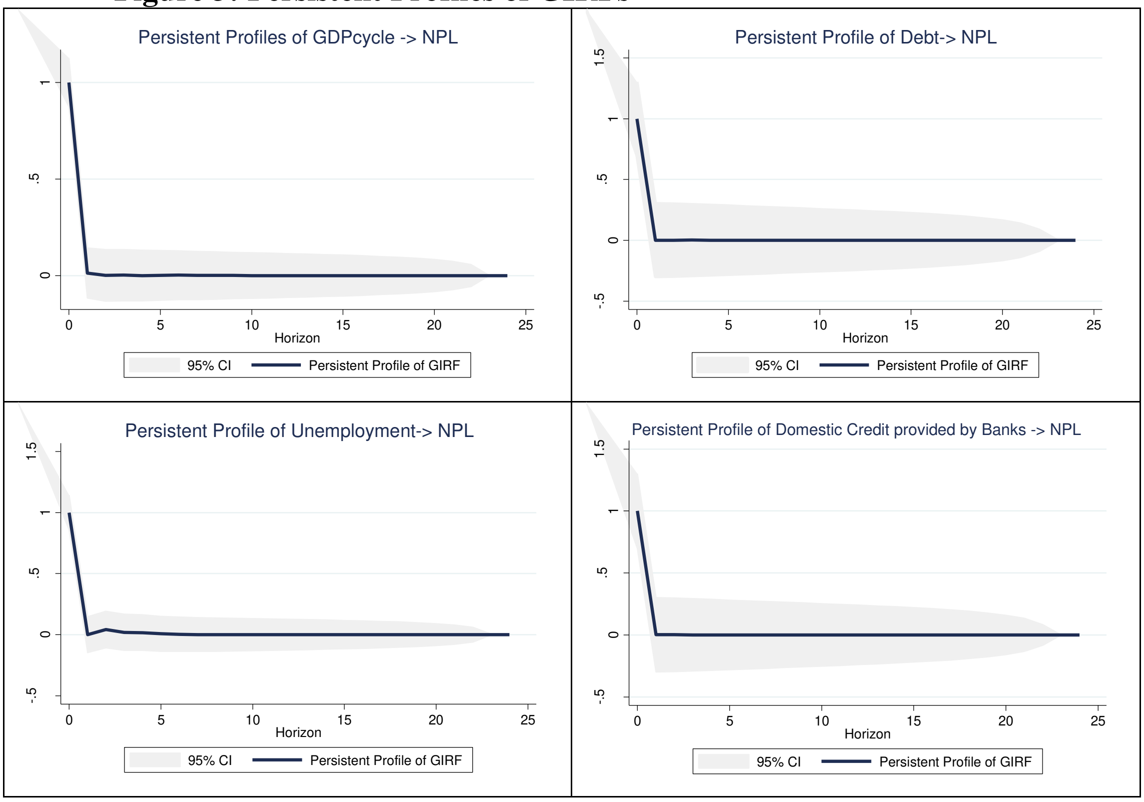
The VEC model is stable, since each eigenvalue of the companion matrix has a modulus less than unity (Fig. 2).

Figure 2: Stability Test of the VEC model



Our findings are also supported by the Persistent Profiles of the respective GIRFs (Figure 3). In general, we do not witness any persistent effects since, as time goes by, the value of each persistent profile tends to zero. In fact, all persistent profiles die outin less than ten (10) quarters, i.e. 2.5 years.

Figure 3: Persistent Profiles of GIRFs



In general, our findings are consistent with international evidence, since we find that both macroeconomic and financial factors have a significant impact on non-performing loans in Greece. Furthermore, we find that public debt is positively related to non-performing loans, suggesting that fiscal problems in Greece are related to the rise of NPLs. Also, our findings show a strong impact of unemployment on the level of NPLs. More specifically, the lack of employment weakens borrowers' ability to (re-)pay their loan installments, thus leading to an increase of problematic loans.

Also, we find evidence that rising NPLs are transmitted to the economy through increases in unemployment (directly through business NPLs and indirectly through households' NPLs). This result is important with respect to understanding the negative self-reinforcing loop characterizing a banking crisis, while having serious implications for stress testing, pointing to the need for considering the second order effects impinging from the banking sector towards the macro environment.

In this context, our findings could be easily used for stress testing exercises by policy makers, including simulation and scenario analyses. For instance, simulation and scenario analyses could be conducted based on the employed macroeconomic and financial variables in order to study the response of NPLs and especially whether they could reach specific thresholds affecting the banking system's ability to grant loans and absorb losses associated with the realization of credit risk.

6. **Conclusion**

In this work, we studied the determinants of NPLs in Greece, on a quarterly basis, in the time period 2001-2015, fully capturing the recent recession by means of a VAR-VEC model, which captures the dynamic interdependencies among the variables used.

According to our findings, both macroeconomic and financial factors have a certain impact on NPLs. We find that public debt and unemployment have a strong impact on the level of NPLs. Also, the empirical evidence suggests that several financial variables, such as domestic credit, seem to have a certain impact on NPLs in Greece, in the time period examined.

Needless to say, our findings are not devoid of policy implications. For instance, it is widely accepted that performance measures could serve as leading indicators of future instability. Hence, the relevant regulatory authorities would be able to use our estimates to detect potential expected NPL increases or decreases based on the macroeconomic and financial determinants that have been found to be the most significant. In such contexts, policy design should take into account the self-reinforcing feedback loops characterizing generalized crises rather than being limited to stress testing exercises and scenarios in which the macroeconomic environment affects uni-directionally banks' balance sheet but the reverse effects are omitted.

Of course, there are several ways in which the present study could be extended. For instance, it could be further investigated whether an endogenously determined structural break could be detected, possibly changing the complex interactions between non-performing loans and their various determinants. Meanwhile, other important financial variables such as spreads (e.g. of sovereign bonds compared to US Treasuries), institutional indicators (e.g. financial deepening), and the role of the so-called shadow banking (i.e. other financial institutions excluding Banks, Insurance Companies and Pension funds) could be investigated.

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