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To my precious Eleni

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Michail-Panayiotis Papafilis

Abstract

The global financial crisis that began in the US as a subprime mortgage crisis in 2007 and quickly spread to the other side of the Atlantic, triggered a sovereign and banking crisis in core and peripheral Eurozone countries. Government authorities and monetary policymakers had a key role during this turbulent period in both sides of the Atlantic, in stabilizing economic activity, strengthening the financial system through credit policy measures, enhancing investment and improving financial conditions.

Further research is needed for this controversial period. In this direction, this dissertation consists of three essays. The first essay focuses on the implications of the recent crisis on the dynamic causal interlinkanges between sovereign and bank credit risk in the Eurozone. The second essay provides an alternative definition of the cost of internal finance, calculates the cost differential between external and internal finance and derives a measure of the equilibrium real interest rate in terms of the cost of internal finance. Finally, the third essay examines the potency of the bank lending and the balance sheet channels in the U.S. during the last two decades.

More specifically, the first essay examines the nexus between sovereigns and banks during the recent crisis period, with a focus on the effects of the Private Sector Involvement (PSI) program, the voluntary exchange program of Greek sovereign bonds with private sector involvement. We investigate the effectiveness of the program through its impact on credit default swaps of eight Eurozone countries and twenty-one banking institutions, using daily data over the period January 2009 to May 2014. Using linear and nonlinear causality analyses, we find that the link between sovereign and bank credit risk weakened after the PSI, while the persistence and magnitude of lead-lag interactions also declined in the same period. A difference-in-difference model confirms this result. Our findings are also robust to second moment filtering, with GARCH-BEKK residuals indicating the presence of significant albeit declining nonlinear causal effects. We conclude that sovereign debt restructuring initiatives, such as the PSI, could be an effective policy measure to ease off pressure on the nexus between banks and their sovereigns, whereby unstable bank balance sheets degrade the solvency of their sovereigns, and vice versa.

In the second essay, we draw a conceptual distinction between the cost of internal finance and the opportunity cost of internal finance, the latter being a fundamental part of the definition of the external finance premium employed extensively in the literature. We come up with an alternative definition of the cost of internal finance and calculate its differential with the cost of external finance. We further investigate the concept of the equilibrium real interest rate and measure it in terms of the cost of internal finance, as the rate that would prevail in the long run after temporary shocks in the economy have died out.

In the third essay, we quantify the amplifying effects of a monetary policy change on real economic activity, due to the operation of the credit channel. These effects are stronger in relation to the case where only the conventional interest rate channel operates. We develop a theoretical framework, based on the Bernanke and Blinder (1988) model, extended to incorporate imperfect substitution between internal and external finance of firms. Our aim is to study the operation of the bank lending and the balance sheet channels in the U.S. over the period January 1994 to June 2017, by using aggregate data. By employing multivariate cointegration techniques and testing appropriate restrictions on estimated equilibrium relationships, we provide evidence that only the balance sheet channel is operational for the periods before and after the global financial crisis.

Περίληψη

Η παγκόσμια χρηματοπιστωτική κρίση που ξεκίνησε στις ΗΠΑ, ως κρίση ενυπόθηκων στεγαστικών δανείων υψηλού κινδύνου το 2007 και γρήγορα εξαπλώθηκε στην άλλη πλευρά του Ατλαντικού, πυροδότησε μια κρατική και τραπεζική κρίση σε κεντρικές και περιφερειακές χώρες της Ευρωζώνης. Οι κυβερνητικές αρχές και οι φορείς χάραξης της νομισματικής πολιτικής διαδραμάτισαν κομβικό ρόλο κατά τη διάρκεια αυτής της ταραχώδους περιόδου και στις δύο πλευρές του Ατλαντικού, για τη σταθεροποίηση της οικονομικής δραστηριότητας, την ενίσχυση του χρηματοπιστωτικού συστήματος μέσω μέτρων πιστωτικής πολιτικής, την αύξηση των επενδύσεων και τη βελτίωση των χρηματοοικονομικών συνθηκών.

Απαιτείται περαιτέρω έρευνα για την κατανόηση αυτής της αμφιλεγόμενης περιόδου. Σε αυτήν την κατεύθυνση, η διατριβή αποτελείται από τρία δοκίμια. Το πρώτο δοκίμιο επικεντρώνεται στις επιπτώσεις της πρόσφατης κρίσης στις δυναμικές αιτιώδεις σχέσεις μεταξύ κρατικού και τραπεζικού πιστωτικού κινδύνου στην Ευρωζώνη. Το δεύτερο δοκίμιο παρέχει έναν εναλλακτικό ορισμό του κόστους εσωτερικής χρηματοδότησης, υπολογίζει τη διαφορά μεταξύ του εξωτερικού και του εσωτερικού κόστους χρηματοδότησης και προσδιορίζει ένα μέτρο του πραγματικού επιτοκίου ισορροπίας με βάση το κόστος εσωτερικής χρηματοδότησης. Τέλος, το τρίτο δοκίμιο εξετάζει την ισχύ των καναλιών τραπεζικού δανεισμού και ισολογισμού στις ΗΠΑ κατά τη διάρκεια των τελευταίων δύο δεκαετιών.

Πιο συγκεκριμένα, το πρώτο δοκίμιο εξετάζει το σχέση μεταξύ χωρών και τραπεζών κατά τη διάρκεια της πρόσφατης κρίσης, με έμφαση στις επιπτώσεις του εθελοντικού προγράμματος ανταλλαγής ελληνικών κρατικών ομολόγων με συμμετοχή του ιδιωτικού τομέα (PSI). Μελετούμε την αποτελεσματικότητα του προγράμματος μέσω της επίδρασής του στις τιμές των παραγώγων αντιστάθμισης πιστωτικού κινδύνου (CDS) οκτώ χωρών και είκοσι ενός τραπεζικών ιδρυμάτων της Ευρωζώνης, χρησιμοποιώντας ημερήσια στοιχεία κατά την περίοδο από Ιανουάριο 2009 έως Μάιο 2014. Χρησιμοποιώντας γραμμικές και μη γραμμικές αναλύσεις αιτιότητας, διαπιστώνουμε ότι η σχέση μεταξύ του πιστωτικού κινδύνου χωρών και τραπεζών περιορίστηκε μετά το PSI, ενώ η εμμονή και η ισχύς των αλληλεπιδράσεων επίσης μειώθηκαν κατά την ίδια περίοδο. Τα αποτελέσματα αυτά

επιβεβαιώνονται και μέσω ενός υποδείγματος difference-in-difference. Τα ευρήματά μας επαληθεύονται επίσης μέσω των καταλοίπων ενός υποδείγματος GARCH-BEKK τα οποία δείχνουν την ύπαρξη σημαντικών, αν και μειούμενων, μη γραμμικών σχέσεων αιτιότητας. Καταλήγουμε στο συμπέρασμα ότι πρωτοβουλίες αναδιάρθρωσης του δημόσιου χρέους, όπως το PSI, θα μπορούσαν να αποτελέσουν ένα αποτελεσματικό μέτρο πολιτικής, προκειμένου να αμβλυνθούν οι πιέσεις στις σχέσεις μεταξύ τραπεζών και χωρών, όπου οι ασταθείς ισολογισμοί των τραπεζών υποβαθμίζουν τη φερεγγυότητα των χωρών τους και αντιστρόφως.

Στο δεύτερο δοκίμιο παρουσιάζουμε μια εννοιολογική διάκριση μεταξύ του κόστους εσωτερικής χρηματοδότησης και του κόστους ευκαιρίας της εσωτερικής χρηματοδότησης, όπου το δεύτερο συνιστά θεμελιώδες μέρος του ορισμού του πριμ εξωτερικής χρηματοδότησης (external finance premium) στη σχετική βιβλιογραφία. Προτείνουμε έναν εναλλακτικό ορισμό του κόστους εσωτερικής χρηματοδότησης και υπολογίζουμε τη διαφορά του με το κόστος της εξωτερικής χρηματοδότησης. Ακολούθως προσδιορίζουμε την έννοια του πραγματικού επιτοκίου ισορροπίας το οποίο μετρούμε με βάση το κόστος εσωτερικής χρηματοδότησης. Πρόκειται για το επιτόκιο που θα επικρατούσε μακροπρόθεσμα μετά την εξάλειψη των προσωρινών αναταραχών στην οικονομία.

Στο τρίτο δοκίμιο, ποσοτικοποιούμε τις ενισχυτικές επιδράσεις μιας αλλαγής της νομισματικής πολιτικής στην πραγματική οικονομική δραστηριότητα, που οφείλονται στη λειτουργία του πιστωτικού καναλιού. Αυτές οι επιδράσεις είναι ισχυρότερες σε σχέση με την περίπτωση που λειτουργεί μόνο το συμβατικό κανάλι του επιτοκίου. Αναπτύσσουμε ένα θεωρητικό πλαίσιο, με βάση το μοντέλο των Bernanke και Blinder (1988), που επεκτείνεται ώστε να ενσωματώνει την ατελή υποκατάσταση μεταξύ εσωτερικής και εξωτερικής χρηματοδότησης των επιχειρήσεων. Στόχος μας είναι να μελετήσουμε τη λειτουργία τόσο του καναλιού τραπεζικού δανεισμού όσο και του καναλιού ισολογισμού στις ΗΠΑ, κατά την περίοδο από τον Ιανουάριο 1994 έως τον Ιούνιο 2017, χρησιμοποιώντας συγκεντρωτικά δεδομένα. Με τη βοήθεια πολυμεταβλητών τεχνικών συνολοκλήρωσης και ελέγχοντας τους κατάλληλους περιορισμούς στις εκτιμώμενες σχέσεις ισορροπίας, δείχνουμε ότι μόνο το κανάλι ισολογισμού λειτουργεί για τις περιόδους πριν και μετά την οικονομική κρίση.

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Introduction

The recent global financial crisis that started in the U.S. in 2007 as a subprime mortgage crisis and expanded in Europe as a twin banking and sovereign debt crisis had significant effects on the stability of the financial system, as well as, on the financial strength of many European countries.

The increase in bank credit risk during the crisis period generated considerable spillover effects on the sovereign sector -especially in Europe- that magnified the results of the crisis. The close links among the Eurozone members and the joint monetary and banking policy by the European Central Bank were conducive to the increase of the potential contagion effects between sovereign and bank credit risk during the last crisis period. Hence, it became imperative for policymakers and bank regulators in the Eurozone to undertake initiatives to attenuate this causal relationship. This would strengthen the stability of the financial system and improve the financial conditions of the stressed European countries. As part of these initiatives, the intervention of the official authorities aiming to reduce the Greek sovereign credit risk before it turned to a systemic risk, through the implementation of the voluntary exchange program of Greek sovereign bonds with private sector involvement (PSI), contributed to this development.

In this context, the main aim of the first essay of this thesis is to study the effectiveness of the PSI program by evaluating changes in the relationship between banks and their sovereigns in Eurozone countries. For this purpose, we employ linear and nonlinear causality methods. In particular, we use the daily credit default swaps (CDS) of eight Eurozone countries and twenty-one banking institutions, over the period January 2009 to May 2014, in order to capture changes in the presence and direction of lead-lag causal relationships, before and after the PSI.

We divide the sample period examined into two subperiods, based on the date of the announcement of the program (October 26th, 2011). To this end, we carry out a battery of tests, including Granger and Hsiao causality tests, tests based on a difference-in-difference model, supplemented by impulse response and forecast error variance decomposition analysis to examine the lead-lag causal relationships between the CDS spreads in a linear framework. The results explicitly reveal that there are strong bidirectional causal effects between sovereign and bank CDS spreads, in the period before the PSI. However, the spillover effects between the CDS series in the post-intervention subperiod appear to have weakened, especially those that arise from the bank CDS to the sovereign CDS spreads. Likewise, impulse response analysis shows significant unidirectional causal effects from sovereign credit spreads to the corresponding banking sector credit spreads in the first subperiod, while in the second the magnitude and the persistence of these lead-lag causal relationships are much lower. Additionally, the strong causal effects running from the Greek sovereign CDS to bank CDS of the other Eurozone countries in the period before the PSI have weakened in the following period. Forecast error variance decomposition results are moving in the same direction. The results of the difference-in-difference model confirm the above indications. Furthermore, we conduct the linear Granger causality test on the estimated residual series that are obtained from the initial vector autoregressive or vector error correction models, in order to eliminate any potential linear causal dynamics. The linear causal linkages have almost been eliminated in both subperiods. This indicates that the initial causal effects between the CDS series are attributed to first moment effects.

In a different methodological approach that has not been used before in the relevant empirical literature, we apply a nonlinear econometric procedure, based on the non-parametric Diks and Panchenko (hereafter D&P) (2006) Granger causality test. Nonlinearities in the transmission mechanism across countries and banks are expected during turbulent periods while significant structural changes are potential sources of a nonlinear causality pattern between them. We consider that the extension of causality tests to a nonlinear framework contributes to better examination of the causal interactions between the CDS time series, capturing more sufficiently, the unpredictable and abnormal variations that occurred in CDS markets under crisis conditions.

We find significant empirical evidence for the existence of a nonlinear structure in the relationship between sovereign and bank CDS series. More specifically, the D&P test results are equivalent to the corresponding linear results in both subperiods. However, we observe that the nonlinear results indicate additional Granger causal relationships that are not captured from the linear causality tests. The implementation of the D&P test on the filtered residuals -after performing first and second moment filtering- confirm the existence of a weak nonlinear causal interrelationship between the CDS series in both subperiods, although the number and the persistence of these causal relationships are reduced, especially in the second subperiod. The existence of causal relationships between the volatility-filtered series (GARCH-BEKK filtering) verifies that the nonlinear causal linkages between the CDS series are not only due to simple volatility spillover effects. We notice that the nonlinear causality tests can capture higher-order causal relationships between the CDS series, by explicitly accounting for increasing bouts of market uncertainty (second moment effects), that cannot be captured in a linear framework.

We observe that the dynamic causal relationships between sovereigns and banks, in terms of magnitude and persistence, weakened after the PSI. Linear and nonlinear causality tests, both in terms of raw and filtered data, provide consistent results. Thus, we conclude that the PSI was successful in weakening the nexus between Eurozone banks and sovereigns.

The other two essays bring us to monetary transmission channels, and in particular to the two components of the credit channel, namely the bank lending channel and the balance sheet channel. The understanding of monetary transmission channels by the monetary authorities is crucial in order to adopt the appropriate policy responses that will contribute to financial stability and growth of the real economy. The bank lending and balance sheet channels operate in an environment of imperfect capital markets in which information asymmetries play an important role. Under conditions of imperfect capital markets, alternative forms of external finance (loans and bonds) are imperfect substitutes for firms and/or banking institutions (bank lending channel), while internal finance (retained earnings) and external finance (equity, loans, debt) are imperfect substitutes for borrowers (balance sheet channel). These conditions reinforce the effects of monetary policy on the real economy, beyond the effects that are attributed to the conventional interest rate channel. For this reason, it is believed that the above imperfections have contributed during the recent crisis period to the reinforcement and propagation of the adverse effects of the crisis to real economic activity. Thus, it is crucial to assess the importance of the monetary policy transmission channels and quantify their impact on the real economy. This is done in the third essay, following the second essay that delves into the concept of the cost of internal finance and into that of the equilibrium real interest rate, which is expressed in terms of this cost variable.

The cost of internal finance is a relevant variable for the balance sheet channel, so in the second essay we provide an operational definition that differentiates it from the ambiguous sense of the opportunity cost of internal finance which is used extensively in the empirical literature, but also from the cost of equity capital, given that equity capital constitutes an external source of corporate finance. The cost of internal finance is used for the specification of the external finance premium. This premium is defined in the literature as the difference between the cost of external finance and the opportunity cost of internal finance, assuming imperfect substitution between these two sources of finance due to capital market frictions. Because there is a cost for lenders to overcome these imperfections, this cost should be passed over to borrowers. Therefore, this approach implies that the cost of external finance should be higher than the cost of internal finance. The higher the dependence on external financing is, the stronger the effects from the operation of the balance sheet channel are.

The cost of internal finance is specified by using the return on retained earnings to firm owners. The (real) cost of retained earnings for a firm in a given period is defined as the sum of the flow of retained earnings and the depreciation flow of this period as a percentage of retained earnings. In this case, the external finance premium is now defined as a cost differential between external and internal finance, which retains the countercyclical property of the external finance premium.

In addition, we use our definition of the cost of internal finance in order to estimate an alternative measure of the equilibrium real interest rate (or natural rate of interest) that is based on a single-variable method. This rate can be considered as the hypothetical (real) cost of internal finance that would prevail in the long run after temporary shocks affecting the economy have died out. We focus on the steady state values of the real interest rate and we specify the equilibrium real rate as the ratio of the depreciation flow, i.e. the amount of earnings required to finance capital consumption in equilibrium, to the stock of retained earnings, over a period which, as indicated, is sufficiently long to allow the effects of shocks to die out.

In the third essay, we use the definition of the cost of internal finance that was introduced in the previous essay, in order to examine empirically the operation of the credit channel in the U.S. for the period from 1994:Q1 to 2007:Q2. The credit channel that works complementary to the interest rate channel, is distinguished into its two components: the bank lending channel and the balance sheet channel.

For our purpose, we develop a model, based on the Bernanke and Blinder (1988) model that allows us to test the operation of the two components of the credit channel simultaneously, by assuming imperfect substitution between forms of external finance (loans and bonds), and between internal and external finance of firms. Also, through this theoretical framework, we are able to calculate the magnifying effects of a monetary policy shift on real economic activity when the bank lending and balance sheet transmission channels are in operation. We show that the effect of a monetary policy shift on total output is greater when these two channels are operational, in relation to the effect when only one of the balance sheet or the interest rate channel is active.

Further, we use multivariate cointegration techniques to identify the equations of our model as equilibrium relationships (cointegrating vectors) among the aggregate time series of our sample. We impose and test a number of appropriate over-identifying restrictions on the structural parameters according to specific theoretical assumptions, which are linked with the operation of the bank lending and balance sheet channels. The results of the stability tests indicate abnormal variations in 2008:Q4, a breakpoint that coincides with the onset of the US financial crisis. Therefore, we study the operation of the credit channel in the pre- and post-crisis periods. The results provide no evidence for the operation of the bank lending channel in any of the two subperiods. Only the balance sheet channel seems to be part of the monetary transmission mechanism for the whole sample period.

Essay 1

The nexus between sovereign and banking risk in the Euro area: The PSI effect

1.1. Introduction

The global financial crisis that began in the US as a subprime mortgage crisis in 2007 and quickly spread to the other side of the Atlantic, triggered an economic and banking crisis in parts of the European Union coincident with a sovereign crisis in parts of the European periphery, most notably in Greece. Banks, which in the years before the crisis, had taken considerable if not excessive risks to expand size and scope in the quest for higher profits, were confronted with adverse pressures incited by a dramatic reduction of liquidity in the interbank money market. With continuing financial market turbulence, falling lending volume, rising defaults, compounded by exposures to distressed sovereigns, European banks found it even more difficult to remain profitable, if not viable in the post-crisis period. Consequently, stronger emphasis was placed on economic support from Government to the banking sector.[1,2] While the ECB's newly established long-term-refinancing-operations (LTRO) program was providing some financial sector relief, nagging concerns were raised about the interconnectedness of Eurozone governments with their banks – a situation

[1] Especially, countries, such as Spain and Ireland, received intense pressure in the first stages of the crisis, due to the need to support their banking systems. The property crash also affected the broader economy and many banking institutions went bankrupt caused by the huge amount of mortgage loans granted.

[2] Alter and Schuler (2012) classify government assistance programs to the financial sector into four categories: "capital injections, guarantees for banks liabilities, asset support programs, and deposit insurance".

that looked set to be further embedded, given how many banks had been willing subscribers to the politicians' view that the LTRO money should be invested in sovereign debt.[3,4] The financial crisis soon turned into a fiscal crisis.

Addressing sovereign solvency problems is much more complex than corporate solvency, since sovereigns cannot be liquidated. And sovereign debt restructuring is more likely to have major repercussions for both the borrower and creditor economies, as evident by international experience beset with disorderly sovereign debt restructuring episodes.[5] In this study, we set out to assess the extent and direction of the relationship between banks and their sovereigns in Eurozone countries during a crisis.[6] More specifically, we focus on the effects of the Greek sovereign debt crisis around a specific event, namely, the 2011/2012 Greek debt restructuring program.

Admittedly, Greece is the Eurozone country which faced the most severe problems since the onset of the financial crisis.[7] The country's potential insolvency would directly affect banks and other creditors with significant exposures to Greek sovereign debt, raising the probability of transmitting risk to private creditors and countries, e.g. a Greek default could trigger 'runs' on other euro sovereigns and their banks, while widening the spreads of sovereign and bank Credit Default Swaps (hereafter CDS). Normally, we would expect that during a financial crisis an increasing share of the variability of sovereign credit risk to be explained by bank credit risk (e.g. see Lahmann, 2012; Vergote, 2016). However, Greece is different insofar the trouble

[3] See The Economist (2011).

[4] Increasing holdings of public debt resulted in the deterioration of bank balance sheets, which coupled with the flight of significant amount of capital, owing to the collapse of investors' confidence in the banking sector, added further pressure to banks.

[5] See Bini Smaghi (2011) who also points out that debt workouts in the public sector are quite different involving not only financial but also political and social adjustment costs.

[6] Paltalidis et al. (2015) provide evidence that sovereign credit risk is the primary source of systemic risk in the Eurozone countries through its effects on the banking system.

[7] The Greek crisis became public in October 2009 after the newly elected centre-left government announced that public finances were far worse than previously thought with the 2009 budget deficit forecast revised upwards from 3.7% (April) to 12% (October) and eventually to 15.6% of GDP, boosting public debt to more than 120% of GDP. By late 2010, it had become fairly clear that any hopes of debt sustainability had quickly evaporated, and at the October 2010 Deauville Summit, the leaders of France and Germany put forth a proposal for the creation of a permanent crisis resolution mechanism inclusive of a sovereign debt restructuring process with the participation of the private sector. While the intent of the new plan was to prevent contagion spreading among Eurozone countries in the event of an ensuing debt crisis by one of the weaker members, the announcement increased turmoil in the financial markets with European periphery bond spreads rising sharply, as investors fretted over wider Eurozone sovereign debt haircuts amidst dismal Eurozone growth prospects.

started from public finances and then moved on to banks. This means we would expect price discovery to move from sovereign to bank CDS recognizing the potential costs of contagion were not limited to the loss of Greek assets only. Countries with weaker banking sectors and public finances (e.g. Ireland, Italy, Portugal and Spain) were particularly vulnerable to contagion.

A series of important measures were put in place during the crisis, aimed at reducing country-specific credit risk, systemic credit risk in the Eurozone, and the strong nexus between sovereign and bank credit risk. Among these measures,[8] was the program of the 'voluntary' exchange of Greek bonds with the participation of the private sector (Private Sector Involvement-PSI-10/2011). The program was unique in several respects owing to (1) its magnitude setting a new record of restructured debt volume and ensuing creditor losses, surpassing the previous mark set by the default and restructuring of Argentina in 2001 and 2005; (2) limited experience in settling sovereign CDS contracts; (3) the credit event occurring after the bond exchange rather than being triggered by an outright payment default; (4) the unusual design of the package of securities offered to investors. The latter comprising a large amount of near-cash EFSF (European Financial Stability Fund) notes, a large number (20 new bond issues under English-law) across a long maturity range, including the 2042 maturity bonds that were ultimately used for CDS settlement (see Zettelmeyer et al., 2013). The entire process, however, was fraught with anxiety, many arguing (e.g. Bini Smaghi, 2011) that there would be no such a thing as an orderly debt restructuring. Adding to this, was the fear that the triggering of CDS contracts would lead to bankruptcies of financial institutions that had written CDS protection similar to what happened earlier on with the collapse of financial institutions in the US that provided CDS protection on CDOs backed by subprime loans (see Gelpern and Gulati, 2012).[9]

[8] Other significant measures in this direction were the following: (a) the unlimited purchase of government bonds by the ECB from the secondary market, for the countries having recourse to the support mechanism (Outright Monetary Transmission (OMT) program-09/2012), (b) the impairment of the private deposits in Cyprus (03/2013), (c) the significant reduction of the interest rates by the ECB (09/2014), which aimed primarily at reducing the credit risk of Eurozone countries and banks, (d) the Single Supervisory Mechanism (SSM), which reinforced the monitoring role by ECB (11/2014), (e) the Emergency Liquidity Assistance (ELA) program, in order to cover the needs of a liquidity-constrained banking system, and (f) the Long-Term-Refinancing-Operations (LTROs).

[9] Contagion fears were reinforced in January 2012, as it became apparent that the exchange was unlikely to be purely voluntary. Taking advantage of the fact that most of the debt (about 86 percent) was issued under Greek law, the Government enacted the Greek Bondholder Act in February of 2012,

The official aim of the PSI was to provide debt relief for Greece, with the objective of reducing the debt to GDP ratio to 120 percent by 2020,[10] by transferring part of the debt burden to the private sector[11] and consequently to private financial institutions, which held a significant amount of Greek public debt in their portfolios. The program was perceived as a strong signal from the International Monetary Fund (IMF) and the European authorities to the private sector, that fully funded bailouts of banks and their sovereigns were no longer tolerable. However, the 'voluntary' participation of the banking sector to the PSI program had important consequences for their capital adequacy ratios because of the replacement of the Greek government bonds that they held in their portfolios, with new ones, whose nominal value was greatly reduced.[12] The situation exacerbated bank credit risk pressure as banks were forced to raise capital at higher cost to offset their investment portfolio losses, commensurate with the rise of sovereign credit risk.[13]

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with a retroactive collective action clause to enable two-thirds investor majority to approve the debt swap deal (amounting to a 53.5 percent nominal haircut) for the entire share of about EUR 206 billion Greek government bonds held by the private sector.

[10] Euro Summit Statement of October 26, 2011.

[11] The press release of the Hellenic Ministry of Finance on February 24, 2012, specifies, in detail, the terms of the PSI program. The new bonds would, necessarily, be governed by English law. Specifically, "the exchange offers and/or consent solicitations will permit private sector holders to exchange bonds selected to participate in PSI for:

(i) new bonds to be issued by the Hellenic Republic on the PSI settlement date having a face amount equal to 31.5% of the face amount of their exchanged bonds,

(ii) European Financial Stability Facility notes with a maturity date of two years or less from the PSI settlement date and having a face amount equal to 15% of the face amount of their exchanged bonds, and

(iii) detachable GDP-linked securities issued by the Hellenic Republic having a notional amount equal to the face amount of each holder's new bonds.

On the PSI settlement date, the Hellenic Republic will also deliver short-term EFSF notes in discharge of all unpaid interest accrued up to 24 February 2012 on exchanged bonds. The Hellenic Republic will not, however, deliver any EFSF notes to holders in the United States of America, who will instead be paid the cash proceeds realized from the sale of the EFSF notes they would otherwise have received. "

[12] There was a significant rise of the sovereign CDS spreads of Greece, as well as those of Ireland, Italy, Portugal and Spain following an announcement at the Euro Summit of 21 July, 2011 that the ECB would not participate in the voluntary PSI program involving an estimated net contribution of EUR 37 billion by banks and insurance companies.

[13] An important element in the program was a promise by the Eurogroup to compensate through recapitalizations Greek banks for their PSI losses, thereby avoiding a major banking crisis in Greece which was more than likely to emerge since Greek banks had already suffered losses of about EUR 38 billion or about 170 percent of their total Core Tier I capital in 2011.

We study dynamic causal interactions between sovereign and bank CDS spreads during the period of the Eurozone sovereign debt crisis. Specifically, we investigate the lead-lag relationship between sovereign and bank credit risk of 8 Eurozone countries and 21 banking institutions during the period January 2009 to May 2014, paying particular attention to the causal effects of the PSI program. For this reason, we split the sample period around the formal announcement of the program on 26 October 2011. The Chow breakpoint test shows that the date of the PSI announcement is a significant structural break in the data, supporting our choice to divide the sample period based on the event date. Using different econometric techniques, we address the following questions. Was the PSI program effective in mitigating the nexus between banks and their sovereigns? Were such effects more pronounced in the causal relationship running from Greek sovereign CDS to bank CDS? Which countries were more vulnerable?

The uncertainty that prevailed in the European financial markets during the crisis period had major effects on sovereign and bank CDS spreads. The announcement of the PSI was a major shift in policy, albeit its effects were uncertain at the time rendering the relationship between spreads to be quite complex and likely nonlinear, recognizing nonlinearities in the transmission mechanism across countries and banks are expected during turbulent periods.[14] Adding to the uncertainty were concerns about the mere size of the Greek PSI program, lack of experience (the first time a major sovereign debt restructuring program being managed away from Washington DC), and complications arising from time delays and amendments to the program from a preliminary version put forth in July 2011, to the formal announcement in October 2011, and the final agreement in February 2012.

We follow a step-by-step procedure to test empirically linear and nonlinear causal relationships between the sovereign and bank CDS series. First, we assess linear causality between sovereign and bank CDS spreads for the periods before and after the PSI program, utilizing Granger and Hsiao causality tests combined with Impulse Response and Forecast Error Variance Decomposition (FEVD) analysis. For robustness, we also employ a difference-in-difference model, to study the causal relationships between the sovereign and bank CDS premiums over the full sample period. Second, we assess nonlinear causal effects between the CDS series in both

[14] See Brunnermeier and Oehmeke (2009) and Brunnermeier and Pedersen (2009).

subperiods applying the nonlinear dependence BDS[15] test and the non-parametric D&P (2006) causality test. In addition, we perform nonlinear causality tests on VAR- or VEC- filtered residuals, thereby removing systematic linear causality patterns from the data. This enables us to check if any observed causality is strictly nonlinear (see Bekiros and Diks, 2008). GARCH effects are a potential source of nonlinearities between the CDS series, which in turn may affect the robustness of causality tests.[16] We filter out autoregressive conditional heteroskedasticity using a bivariate GARCH-BEKK (1,1) model and re-run the non-parametric causality test using standardized residuals.[17] Our aim is to capture higher-order causal relationships by using volatility-filtered series, so that we are able to ascertain if nonlinear causal relationships in the data persist after second moment filtering rather than being driven purely by volatility spillover effects.

Our tests reveal significant linear and nonlinear dynamic causal relationships between the CDS series. We find causal effects to be bidirectional in the majority of cases, especially during the first period, and this finding is preserved as we move from linear to nonlinear causality testing. We observe a public-to-private risk transfer consistent with the aim of PSI. In particular, we find that the strength of both linear and nonlinear causal effects between banks and sovereigns appears to ease-off in the period following the implementation of the PSI program. Moreover, we observe that volatility spillovers underpin the nonlinear Granger causal relationships. However, the interconnectedness between the series persists after first and second moment filtering. This implies that any nonlinear causal linkages between the CDS series are not solely due to volatility effects. We conclude that the PSI appears to have had some success in containing the nexus between sovereign and bank credit risk during the sovereign crisis.

This study contributes to the existing literature in two directions: First by applying a more comprehensive econometric approach comprising linear and nonlinear causality tests to analyze the nexus between banks and sovereigns, and second by providing

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[15] Brock, Dechert, Scheinkman and LeBaron (1996).

[16] D&P (2006) contend that the existence of conditional heteroskedasticity in the data may lead to spurious causality test results recognizing that causality maybe be confounded by conditional volatility.

[17] Many financial series are characterized by time-varying conditional variance exhibiting clustering, especially series measured at higher frequencies. As we use daily data on sovereign and bank CDS spreads, it is prudent that we control for GARCH effects.

new empirical evidence on the relationship between sovereign and bank credit risk in view of an important policy intervention, the PSI effect. The nonlinear econometric framework extends previous research by capturing the complex interlinkages between the CDS series during a period of highly volatile conditions. Specifically, we examine if a significant event, such as the PSI program has affected the linear and nonlinear interconnections between sovereign and bank credit risk. We provide evidence that the nexus between sovereigns and their banks weakened rather than amplified after the implementation of PSI. This finding is important since widely held views at the time were very pessimistic about the outcome of the program. A similar tool could be used in future crises by policy makers, in order to minimize the contagion effects between sovereign and bank credit risk contributing to sovereign creditworthiness and financial stability.

The remainder of the essay is structured as follows. Section 2 reviews the existing literature on the relationship between sovereign and bank credit risk leading to the development of our main testable propositions. Section 3 describes the data. Section 4 presents the methodology, while Section 5 discusses the empirical results. Section 6 summarizes the main conclusions.

1.2. Literature review and hypotheses development

Since the global financial crisis, much empirical research in cross-country studies has focused on the relationship between sovereign and bank credit risk. The consensus is that this relation has developed beyond a simple local affair into interdependence and contagion between countries and banks.

Contagion is an elusive concept with several definitions on offer in the literature.[18] The World Bank, for example, regards that contagion occurs when transmission of shocks between countries increases in times of crisis, compared to the corresponding transmission in tranquil periods.[19] Constâncio (2012) defines financial contagion as a situation in which instability in a specific market or institution is transmitted to one or several other markets or institutions, with the transmission process causing non-

[18] In the empirical literature a number of different methodological approaches have been employed for testing contagion, including cross-market correlation analysis, VAR models, conditional probability models, volatility changes, probit models, principal components, latent factor models, among others. Dungey et al. (2005) provide a detailed review of different methods used to identify contagion.

[19] www.econ.worldbank.org.

expected, abnormal relationships between markets or intermediaries. In the same vein, Forbes and Rigobon (2002) define contagion as an extraordinary increase in cross-market linkages after a shock to one country or a group of countries. In the case where the co-movement remains stable after a shock in relation to a tranquil period then any increase in the correlation between two markets or economies is due to the existence of interdependence. In this case, the transmission mechanism is driven by market fundamentals.[20]

Since we focus solely on a crisis period, it is reasonable to assume that there has been already a structural change in the transmission process.[21] Hence the question is one of degree and scope, viz. whether contagion risk was heightened and widened across countries and banks in the transition from the financial to the sovereign crisis (e.g. as a result of a shift from a bad equilibrium before PSI to another bad equilibrium after PSI). As in Sander and Kleimeier (2003), we use a narrow definition of contagion focusing on changes in the presence and direction of causality during different phases of a crisis, while maintaining the assumption that multiple equilibria may exist.

Masson (1998) contends that a crisis in one country or market could influence investors' expectations causing contagion effects and spreading the crisis to another country or market due to a shift from a good to a bad equilibrium. These expectations are not driven by changes in macroeconomic fundamentals - as may be the case under a good equilibrium - but emanate from uncertainties about multiple equilibria. Based on this approach, contagion arises when self-fulfilling beliefs about bad equilibria locally are diffused to other countries or markets, with contagion effects expected to be more pronounced in countries or institutions with weaker economic fundamentals. This is arguably the case in Greece where both the sovereign and its financial institutions were in serious trouble because of rapidly worsening economic conditions, whereby a bad situation was getting worse because of loss of confidence and increasing investor risk aversion.

[20] Corsetti et al. (2005) contend that contagion arises due to financial panics, herd behavior, or as investor expectations shift across instantaneous equilibria.

[21] As evident from the sharp rise of CDS spreads and their volatility in the European periphery which may be difficult to reconcile on the basis of fundamental drivers, recognising that economic conditions (i.e. market fundamentals) in the majority of these countries were only changing gradually (Delatte et al., 2014).

During normal times, we would not expect a strong relationship between bank and sovereign CDS, with the causality more likely to run from bank CDS to sovereign CDS rather than the other way around. However, this is likely to change during crisis periods, especially with increasing incidence of stress in the banking system coupled with weak fiscal fundamentals. A host of studies provide evidence on the nexus between banks and their sovereigns. Ejsing and Lemke (2011) investigate default risk of sovereigns and banks for 10 Euro area countries. They identify significant public and private risk transfer, using a common risk factor (the iTraxx index of non-financial CDS premia). They find that bank CDS spreads decrease, while the corresponding sovereign CDS spreads increase following the announcement of bank rescue packages. Similarly, Alter and Schüler (2012) analyzing CDS spreads of six Eurozone countries and their domestic banks find that in the period before the bailout of financial institutions, sovereign credit risk is driven mainly by bank credit risk. However, this result is reversed in the period after the bailout of the banking sector.

Acharya et al. (2014) examine causal effects between sovereign and bank credit risk of Eurozone countries during the period 2007 to 2011. They find that the greatest concern stems from cross-border bank exposure to private sector risk. They also report that bank rescue packages reinforce the interconnection between bank credit risk and the corresponding sovereign risk, as sovereign CDS spreads rise while bank CDS fall. Kallestrup et al. (2016) show that there is a significant unidirectional causal relationship from exposures of domestic banks to foreign sovereign CDS premiums. Dieckmann and Plank (2012) highlight the private-to-public risk transfer in 18 European countries that have taken stringent measures during the crisis to restore financial stability. They point out that the risk transfer is greater for countries with larger exposures to their financial system in the pre-crisis period, particularly countries that are members of the European Monetary Union.

In contrast, Demirguc-Kunt and Huizinga (2010) highlight the reverse risk channel from sovereigns to banks using an international sample of banks. They find that bank CDS spreads in fiscally strapped countries rose remarkably during the financial crisis, and this occurred because these countries were deemed fiscally weak to safeguard financial stability. Lahmann (2012) also provides evidence of interdependence between sovereign and bank credit risk at a global level for the period October 2005 to April 2011. He shows that, after the outbreak of the debt crisis, interactions between CDS spreads have intensified, with the effect of bank risk on sovereign risk becoming stronger as countries become increasingly exposed to the contingent liabilities of the banking sector.

In a recent study, Yu (2017) using a sample of 11 European countries and 26 commercial banks from 2006 to 2012 finds no significant interaction between sovereign and bank CDS spreads in the period before the financial crisis. However, the causal effects become significant after the onset of the subprime crisis. She provides evidence that a sovereign default is likely to cause a banking crisis; while on the other hand, bank guarantees and taxpayer funded bailouts may cause a sovereign debt crisis. She concludes that before the bankruptcy of Lehman Brothers, bank CDS spreads were the leading factor influencing sovereign CDS spreads, while during the Eurozone debt crisis, sovereign CDS spreads assume this role.

Alter and Beyer (2014) use generalized impulse response functions to examine the interdependence between European sovereign and bank credit markets. They form a contagion index to capture the spillover effects between sovereigns and banks in the Eurozone. They show that during the sovereign debt crisis, the interaction between CDS spreads increases significantly, while policy interventions diminish the spillover effects between sovereigns and banks. Similarly, Vergote (2016) applies Granger causality tests to study the spillover effects between sovereign and financial credit risk in the Euro area based on fair-value CDS spreads. He constructs a time-varying contagion index that controls for common factors. He shows that there are significant feedback causal effects between sovereigns and financial institutions. However, the spillover effects from sovereigns to financial institutions are reduced, after policy interventions aimed at confronting the European sovereign crisis. On the other hand, the effects from the financial sector to the sovereigns are not diminished, despite banking sector reform.

Drawing on previous evidence on public to private risk transfer coupled with the complexities and uncertainties surrounding the PSI program, we set forth to assess empirically the following propositions:

P1. The nexus between sovereigns and their banks is expected to be stronger in the period after the PSI announcement.

More specifically, we would expect:

P1a. Causality to run stronger from sovereign to bank CDS after PSI;

P1b. The effect under P1a to be more pronounced in countries with weak fiscal fundamentals.

However, an argument can be made in support of the PSI, recognizing that well designed and well supported debt restructuring programs may be successful in reducing market uncertainty and hence the nexus between banks and their sovereigns. Admittedly, Greece had reached a point of distress making a default almost unavoidable with the overriding question being one of collateral damage inflicted on private creditors, mainly financial institutions, but also on other sovereigns through contagion. With Italy and Spain dragged into the crisis by mid-2011, decisive action was imperative to deal with an increasingly dire situation. While not problem free, the PSI program was embedded with sufficient sweeteners to creditors to make best of what was feasible under the circumstances, avoiding the financial collapse of Greece while minimizing risks to other sovereigns (Zettelmeyer et al., 2013). Following from this, a competing proposition may be stated as:

P1c. The nexus between banks and their sovereigns will be weaker after PSI.

Note we are not suggesting that CDS spreads will be lower in the immediate period following the PSI announcement, irrespective of whether the program is ultimately deemed to be successful or not. We recognize that there is high degree of uncertainty surrounding a major debt restructuring initiative, from its announcement to the period immediately after its implementation. With the benefit of hindsight, the program was successful in achieving 96.9 percent participation on the total nominal debt amount, in part as a result of attractive terms such as a near cash offer of EUR 15 billion in short-term EFSF securities, an upgrade of governing law with new bonds of varied maturities issued under English rather than Greek law, and more importantly a co-financing agreement with EFSF which in essence meant that it would not be possible for Greece to default on the new bonds without at the same time defaulting on the EFSF loan. An added feature to the program, and one that would enhance greater creditor participation was a clause ascertaining that no CDS would be triggered before the bond exchange was initiated.[22]

[22] According to Coudert and Gex (2013), the main reasons for this “bloodless” settlement were the following: the arrangement concerned only the net positions of the investors, protection sellers did not

The above propositions focus on the dynamics of the relationship between sovereigns and their banks, exploring differences, if any, they may exist across different countries. The next set of propositions focus specifically on the effects of Greek sovereign risk on European banks risk. Previous studies, e.g. Tamakoshi and Hamori (2013) analyze causality between the CDS index of the banking sector of the Eurozone and the sovereign CDS spreads of Greece, for the period of 2008 to 2011. Before the debt crisis, they identify unidirectional transmission of credit risk from bank CDS to the sovereign CDS spreads of Greece. However, during the crisis, the situation is different as there is a significant influence of Greek sovereign CDS spreads on bank CDS. Similarly, Bhanot et al. (2014) find that an increase in Greek sovereign yield spreads during the turbulent crisis period had significant spillover effects on the financial sectors of different Eurozone countries. Drawing on such evidence in tandem with the uncertainties surrounding the PSI program, we set forth to assess empirically the following propositions:

P2a. Causality from Greek sovereign CDS to bank CDS spreads is expected to be stronger after the PSI program announcement.

P2b. Causality under P2a will be stronger for countries with weaker fiscal fundamentals.

A competing proposition views PSI as a window of opportunity for placing Greek debt on a more sustainable footing. Hence an alternative proposition may be stated as:

P2c. Causality from Greek sovereign CDS to bank CDS spreads is expected to be weaker after PSI.

The majority of studies in the empirical literature use parametric linear Granger causality tests based on VAR models to examine the causal linkages between sovereign and bank credit risk. However, nonlinear feedback relationships are likely to be more pronounced during financial crises.[23] Nonlinear causality tests have been developed by Baek and Brock (1992), and modified by Hiemstra and Jones (1994)

have extra demands as guarantees for this settlement due to regular margin calls, bond-holders were compensated for their shortfalls by protection sellers to the face value of their bonds.

[23] Brock et al. (1991) contend that nonlinear causality tests are able to detect the existence of higher-order causal relationships between the series, in contrast to those solely focusing on the conditional mean, such as the linear Granger causality test. This is important since linear causality tests may incorrectly identify a unidirectional relationship between two series when in fact the relationship may be nonlinear and bidirectional (see Hiemstra and Jones, 1994).

(hereafter H&J) to allow each series to exhibit weak temporal dependence. Diks and Panchenko (2005) show that the H&J test tends to over-reject the non-causality null hypothesis, since it does not take into account the possible variation in conditional distributions under the null, especially when the size of the sample increases and bandwidth values are low. In a follow up paper, D&P (2006) propose a non-parametric causality test as a modified version of the Baek and Brock (1992) and H&J tests.

Dajcman (2015) investigates nonlinear interdependence between sovereign bond markets in the Eurozone during the European sovereign debt crisis using the D&P nonlinear Granger causality test. The results show that there are significant linear and nonlinear causal effects between the time series for the period before the crisis, while spillover effects decline in the period after the onset of the sovereign debt crisis. Chen et al. (2013) apply linear and nonlinear Granger causality tests - both H&J and D&P tests - to study the causal relationship between banks and insurers in the U.S. for the period 2001 to 2011, focusing on the systemic risk of the insurance and banking sectors. Despite the fact that they initially observe significant causal relationships between the CDS series, the findings vary when they adjust the data for conditional heteroskedasticity. They find that the effects of banks on insurers are now longer and stronger than the corresponding effects from insurers to banks.

Caporin et al. (2013) use sovereign CDS spreads to study nonlinearities in the transmission of sovereign credit shocks in the Eurozone. Applying nonlinear, quantile and Bayesian quantile regressions that allow for heteroskedasticity, they find no evidence of change in the intensity of the transmission of shocks since the onset of global financial crisis. They interpret this finding as absence of sovereign risk contagion among Eurozone countries recognizing their sample period ending just before the PSI announcement, may not be long enough to identify significant changes in the propagation mechanism.[24] Amisano and Tristani (2011) study nonlinearities in the transmission of sovereign credit risk in the Eurozone using a regime-switching model over the period January 1999 to December 2010. Their model captures abnormal variations of sovereign yield spreads after a shift from a 'normal' to a

[24] Kenourgios et al. (2011) based on an alternative methodological framework use a multivariate regime-switching Gaussian copula model and the asymmetric generalized dynamic conditional correlation (AG-DCC) approach, in order to capture nonlinear cross-country contagion effects.

'crisis' regime. They find that the probability of entering the crisis regime increases when a country's fiscal position worsens, and this increase is amplified by contagion mainly driven by an increase in market risk aversion.

Billio et al. (2012) apply bivariate linear and nonlinear Granger causality tests and principal component analysis using monthly stock returns of hedge funds, brokers/dealers, insurance companies and banks, to model the diffusion of the systemic risk during the financial crisis. They find significant causal linkages among the different financial sectors. Furthermore, they model the interconnectedness among countries, banks and insurance institutions in a multi-country framework, by using credit spreads. Based on contingent claim analysis and network measures, they show that there are significant dynamic interactions among sovereigns, banks and insurance companies during the global financial crisis and the European sovereign crisis. However, the effects arising from sovereigns to banks and insurers are more significant during the European sovereign debt crisis.

Recognizing the nonlinear structure in bank and sovereign CDS spreads, we assess empirically the following propositions:

P3. Nonlinear causal interlinkages between sovereign and bank CDS are expected to be amplified after PSI.

More specifically:

P3a. Nonlinear causal effects from sovereign to bank CDS are expected to be amplified after PSI.

P3b. The effects under P3a may be driven by volatility spillover effects.

A competing proposition may be stated as:

P3c. Nonlinear causal interlinkages between sovereign and bank CDS are expected to weaken after PSI.

Conclusively, the nonlinear approach contributes to a better quantification of the effects of an economic policy action - such as the PSI - by specifying the dynamic relationships between sovereign and bank CDS series. It provides us with some useful insights about the effectiveness of such measures.[25] Moreover, the significant increase in investor risk aversion and the rise of self-fulfilling expectations also account for

[25] Kyrtsou and Labys (2006).

nonlinearities in the CDS relationships. To our knowledge, this is the first study using nonlinear causality tests to investigate empirically contingent Granger causal linkages in the relationship between sovereign and bank CDS spreads in the Eurozone. More specifically, we apply the non-parametric causality test of D&P (2006) to examine for nonlinear interactions between the CDS series of our sample.

1.3. Data description

We use daily prices of senior unsecured sovereign CDS spreads on 5-year government bonds, considered as those with higher liquidity,[26] and the respective senior unsecured bank CDS spreads. The sample period ranges from 1 January 2009 to 30 May 2014. The higher the value of CDS spreads, the less likely a country or a banking institution will be able to meet its debt obligations. In the empirical literature, we observe that CDS premiums have established as the main proxy for credit risk, since the inception of the global financial crisis.[27]

We extract daily data on CDS spreads from Thomson Reuters Datastream and Bloomberg. In our analysis, we consider those countries of the Eurozone that experienced major debt problems during the recent financial turmoil, viz. Portugal (PT), Italy (IT), Ireland (IR), Greece (GR), and Spain (SP) known by the acronym PIIGS. Moreover, we include, the Netherlands (NL), France (FR) and Germany (DE). These countries possessed in their portfolios major shares of PIIGS debt. The selection of the sample of banking institutions in each country is based on their total assets and on the availability of the data for the period under review (see Table A1 in the Appendix).

The CDS spreads are expressed in basis points (bps) and transformed into natural logarithmic values[28] recognizing the wide variations in spreads for some countries and banks during the period of analysis. We weigh the bank CDS spreads in our sample by using their total liabilities in each year to calculate the index of bank CDS spreads for each country. Furthermore, in order to study the nexus between the CDS series at the aggregate level, we calculate new CDS series by weighting the sovereign CDS spreads for the eight Eurozone countries based on their gross domestic product each

[26] Hull, Nelken and White, (2004).
[27] Fontana and Scheicher, (2010).
[28] Forte and Pena, (2009).

year, and the corresponding banking sector CDS spreads according to the annual liabilities of each banking institution. For robustness, we also employ the unweighted sovereign and bank aggregate CDS series.

To analyze changes in the lead-lag interaction between sovereign and bank credit risk as a result of the PSI program, we divide the reporting period into two subperiods. The break point is determined exogenously to be 26 October 2011, the date of the announcement of the decision of the European Summit for the implementation of the ‘voluntary’ exchange program of Greek bonds with the participation of the private sector. Chow breakpoint test results verify that this date is a significant structural break in the relationship between all pairs of CDS series.

Figures 1.1 and 1.2 illustrate the evolution of the log CDS series (multiplied by 100) during the sample period. The vertical line indicates the PSI announcement date that separates our sample. It is evident that the CDS series of most countries and banks are close to their maximum levels around the PSI period; however, they start to decline soon after. Greek sovereign CDS spreads continue to rise to exceptional levels during the period of the PSI program although they too decline eventually. The steep rise of Greek sovereign CDS spreads in March of 2010 is indicative of heightened concerns about a Greek sovereign default, with the country losing access to the bond markets in April 2010. The effects are spreading to other Eurozone countries, especially those with weak fiscal fundamentals, triggering large increases in Italian, Irish, Portuguese and Spanish sovereign CDS premia. Although, France, Germany and the Netherlands have stronger fundamentals, we observe a similar upward trend in their CDS spreads during the period leading the PSI program, recognizing riskiness is pervasive in the derivatives market. CDS premia reached very high levels during the third quarter of 2011, indicative of the market’s perception of disorderly restructuring spilling into other credit markets.

We observe a high degree of co-movement between Greek sovereign and bank CDS series for the whole sample period, albeit banking sector CDS spreads do not rise as high as sovereign CDS. Irish banks exhibit the highest CDS premia. In fact, they are higher than Irish sovereign CDS throughout the entire period. German and Dutch banks exhibit the lowest CDS premia. The concurrent variation of the sovereign and bank CDS spreads are indicative of the strong interlinkages between government and bank credit risk. Most of CDS series decrease during the second quarter of 2012 after the implementation of PSI (completed on 25 April 2012).

Figure 1.1 Daily sovereign log CDS series multiplied by 100
01/01/2009-30/05/2014

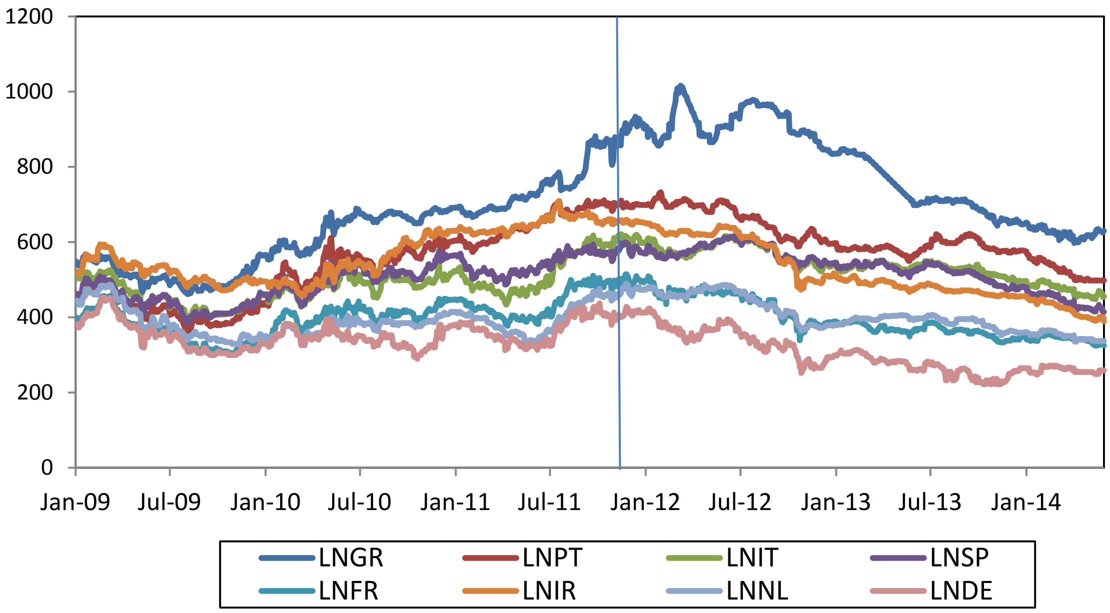

Figure 1.2. Daily bank log CDS series multiplied by 100
01/01/2009-30/05/2014

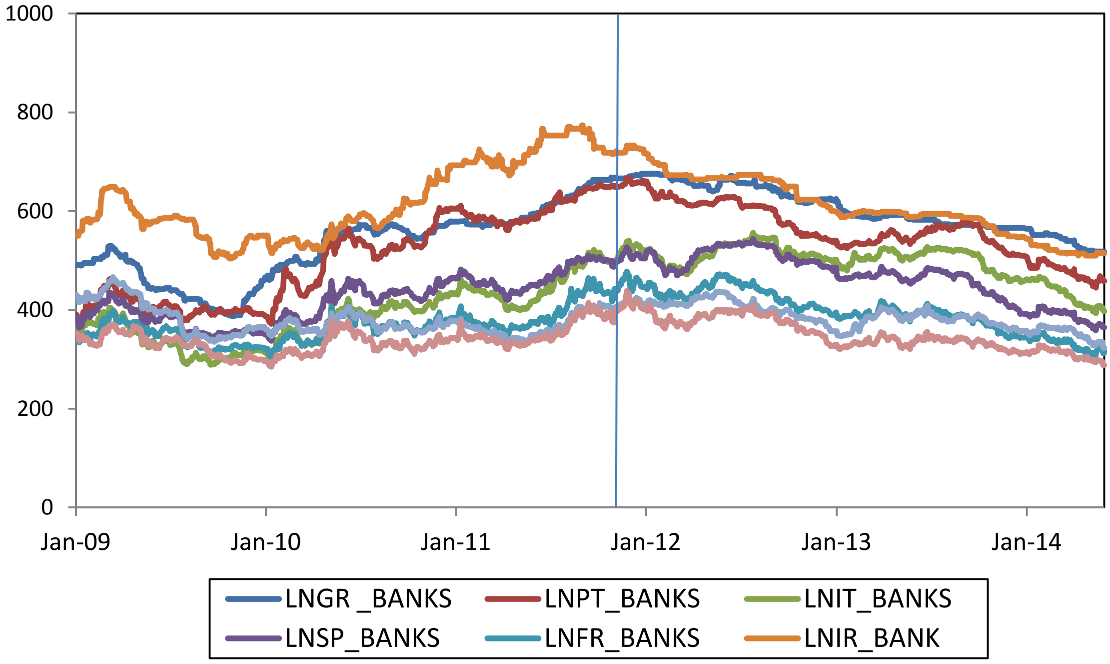

Table 1.1 reports the descriptive statistics of the sovereign and bank CDS spreads in our sample. We observe that the spreads increase significantly during the second subperiod, except for the sovereign and bank spreads of Ireland and the sovereign spreads of Germany. The average sovereign CDS spread in the first subperiod is 253bps, while in the second subperiod is 857bps, which is mainly due to the surge of the Greek risk premium. The corresponding averages, excluding Greece, are 161bps and 208bps. Aside from Greece, sovereign CDS of Italy, Portugal and Spain are much higher in the second period. The bank CDS spreads averages are 174bps and 221bps, for the first and the second subperiod, respectively. Standard deviations also increase in the second subperiod indicative of intensified volatility, uncertainty and risk. In contrast, the standard deviations are lower for Irish, Portuguese and Dutch banks during the second subperiod.

Table 1.1: Descriptive statistics

Panel A: Descriptive statistics of sovereign CDS spreads - Period 1 (1 Jan 2009 – 26 Oct 2011)

Variable	Obs	Mean(bps)	Std. Dev.	Min(bps)	Max(bps)	Skewness	Kyrtosis
GR	735	900.47	1168.94	100.27	6751.79	2.99	12.40
PT	735	320.48	304.39	37.00	1227.89	1.36	3.98
IT	735	141.66	79.05	48.00	482.04	1.90	6.73
SP	735	158.26	76.90	47.00	378.81	0.60	2.53
IR	735	356.87	237.85	96.92	1191.15	0.88	2.81
FR	735	60.53	29.28	21.00	164.93	1.19	4.48
NL	735	51.93	23.63	26.49	130.00	1.49	4.55
DE	735	36.74	14.86	17.96	92.50	1.41	4.95
AllCountries (Weighted)	735	112.51	68.50	36.09	387.09	1.88	6.95
AllCountries (Unweighted)	735	253.37	226.03	54.03	1225.02	2.16	7.96

Panel B: Descriptive statistics of bank CDS spreads - Period 1 (1 Jan 2009 – 26 Oct 2011)

Variable	Obs	Mean(bps)	Std. Dev.	Min(bps)	Max(bps)	Skewness	Kyrtosis
GR_Banks	735	250.20	173.34	48.11	797.88	1.23	4.35
PT_Banks	735	218.02	178.76	37.44	690.08	0.92	2.87
IT_Banks	735	56.25	35.25	17.94	183.64	1.49	5.08
SP_Banks	735	72.69	33.52	29.28	165.42	0.84	3.11
IR_Banks	735	677.74	567.48	155.00	2298.98	1.23	3.39
FR_Banks	735	40.56	14.58	21.06	103.98	1.72	6.47
NL_Banks	735	45.38	15.75	25.65	106.03	1.60	5.18
DE_Banks	735	30.07	8.16	17.30	63.03	1.32	5.04
AllBanks (Weighted)	735	58.56	25.69	26.20	144.61	1.22	4.20
AllBanks (Unweighted)	735	173.86	121.18	47.88	507.27	1.11	3.17

Panel C: Descriptive statistics of sovereign CDS spreads Period 2 (27 Oct 2011 – 30 May 2014)

Variable	Obs	Mean(bps)	Std. Dev.	Min(bps)	Max(bps)	Skewness	Kyrtosis
GR	677	5399.97	5432.59	391.63	25960.76	1.22	3.99
PT	677	557.90	348.21	143.95	1521.45	0.81	2.21
IT	677	249.67	106.21	87.73	498.66	0.59	2.32
SP	677	233.47	106.31	62.83	492.07	0.33	2.30
IR	677	261.51	212.75	48.65	729.19	0.84	2.08
FR	677	62.66	36.96	25.79	171.56	1.01	2.76
NL	677	65.11	30.51	28.46	133.84	0.74	2.10
DE	677	24.63	15.48	9.16	72.35	1.26	3.52
AllCountries (Weighted)	677	239.69	168.75	50.84	744.72	0.73	2.41
AllCountries (Unweighted)	677	82.30	31.27	31.40	158.34	0.29	1.99

Panel D: Descriptive statistics of bank CDS spreads Period 2 (27 Oct 2011 – 30 May 2014)							
Variable	Obs	Mean(bps)	Std. Dev.	Min(bps)	Max(bps)	Skewness	Kyrtosis
GR_Banks	677	476.85	214.78	177.04	859.49	0.41	1.70
PT_Banks	677	322.84	172.93	85.83	799.67	0.78	2.65
IT_Banks	677	152.05	45.78	51.00	259.74	-0.35	2.52
SP_Banks	677	121.02	50.46	36.17	230.19	0.11	2.09
IR_Banks	677	551.54	340.55	163.99	1530.14	1.03	3.36
FR_Banks	677	58.61	23.50	21.57	118.19	0.44	2.29
NL_Banks	677	49.49	12.44	25.27	79.46	0.32	2.33
DE_Banks	677	35.78	12.44	17.82	80.19	0.75	2.61
AllBanks (Weighted)	677	768.29	725.02	100.52	3560.48	1.11	3.59
AllBanks (Unweighted)	677	221.02	103.64	72.80	471.13	0.55	2.24

Overall, we observe that the sovereign credit spreads are at a higher level in relation to the corresponding bank spreads in both subperiods, with the exception of the CDS spreads of the Irish banks for both periods and those of the German banks for the second period. This reflects higher government credit risk, during the European debt crisis, in relation to the bank credit risk. Standard deviation results do not diverge significantly.

The high values of kurtosis indicate that the CDS spreads change remarkably quite often. This is a sign of the increased probability of observing outliers, particularly in the first subperiod, and, of the amplified credit risk. We notice positive skewness for all the time series, except for the Italian bank CDS in the second subperiod. Consequently, there are a few high outliers in relation to the large number of low prices in our sample. This is an indicative element of the turmoil that prevailed, especially, in the first subperiod.

Observing the results of pairwise correlations of sovereign and bank CDS spreads in their logarithmic first-differences, as presented in the Table A2 in the Appendix, we find significant correlations, greater than 0.3 between all pairs of series -except for

Greece and Ireland- during the second subperiod. In total, we observe that there is a considerable reduction in the correlation between the CDS spreads the period after the implementation of the PSI.

1.4. Methodology

1.4.1. Stationarity and cointegration

In order to apply the linear and nonlinear causality tests, aiming to ascertain the presence of causal effects between the sovereign and the corresponding bank CDS spreads in each subperiod, we have to test for stationarity the time series of our sample, by applying unit root tests. We examine the stationarity properties of the (log) level CDS series applying the Phillips-Perron[29] (PP), Augmented Dickey-Fuller[30] (ADF) tests (under the unit root null) and for robustness, the Kwiatkowski-Phillips-Schmidt-Shin[31] (KPSS) test (under the stationarity null) in each subperiod.[32] We accept that the time series has a unit root, when at least two of the above tests prove the existence of a unit root at the 5% significance level. In case a variable has a unit root in levels, we calculate the logarithmic first-differences and we repeat the same unit root tests, in order to achieve stationarity.

If we conclude that the time series are integrated of order one, i.e. I(1), then we test for cointegration between the non-stationary CDS series applying the Johansen (1995) trace and maximum eigenvalue tests for each subperiod.[33] The time series are cointegrated if at least one of these tests provides evidence of cointegration at the 5% significance level. We recognize that using a cointegration approach over a relatively short period may entail some problems. Nevertheless, we believe it is justified given the high-frequency data we employ, in particular since the resulting cointegrating

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[29] Phillips and Perron, (1988).

[30] Dickey and Fuller, (1979).

[31] Kwiatkowski, Phillips, Schmidt and Shin, (1992).

[32] We split the sample period based on the Chow breakpoint test. The Chow test examines the null hypothesis that there is no break in the regression coefficients. It estimates the sum of squared residuals after fitting a single equation to the complete sample, in relation to the sum of squared residuals raised after each single equation is fitted independently to each specified subsample.

[33] Chen and Lin (2004) draw attention to the possibility that misleading conclusions about causal relationships may be drawn if the cointegration relationships between the CDS series are not accounted for in the causality test.

relationships could be interpreted as reflecting systematic temporary patterns.[34] We select the number of lags based on the Akaike Information Criterion (AIC).[35]

The null hypothesis of the trace test is H_0: $r \leq r_0$ for $r_0=0,1,...,n-1$, where n is the number of variables. This test examines that the maximum number of cointegrating vectors are r_0, versus the alternative hypothesis that there are more than r_0, H_1: $r_0<r \leq n$. Since the series are cointegrated, there could be up to n-1 combinations of cointegrating relationships. Therefore, in our study where we examine two variables (n=2) -sovereign and bank CDS series-, there can be up to one cointegrating vector. Consecutively, we check for $r_0=0$ and $r_0=1$. The control stops at the value of r_0 that H_0 is accepted.

Regarding the application of the maximum eigenvalue test, the H_0 hypothesis is the same as in the trace test. However, the H_1 assumes that there are exact r_0+1 cointegrating vectors. If after performing the Johansen tests, we find that $r_0=n$, this implies that the variables are stationary in levels (i.e. I(0)). During these tests, we include a constant (intercept) in each cointegrating equation, which is more plausible to reflect the generating mechanism of the data.

1.4.2. Linear causality

1.4.2.1. Linear Granger causality

Observed correlation between two CDS series under consideration does not imply the existence of a causal relationship between them. As per standard practice, we first study the causal relationship between CDS series using the notion of Granger causality (1969) based on a time lag between cause and effect. The existence of Granger causality between time series, means that all recent and past information of the one time series contribute to a better prediction of the future values of the other, not in the narrow sense that the one variable provokes changes to the other.[36]

Specifically, for a strictly stationary bivariate time series process $\{(X_t,Y_t)\}$, $t \in \mathbb{Z}$, {Xt} Granger causes {Yt}, if for some $k \geq 1$:

[34] See Sander and Kleimeier (2003) who justify their approach on similar grounds.

[35] The selection of the appropriate lag length should be carried out very carefully, as there is risk of a biased estimation of the cointegrating vector (Jacobson, 1995).

[36] Brooks (2008) notes that the definition of Granger causality simply implies a chronological ordering of moments in the series, which in essence captures the lead-lag pattern between the series, rather than the real causal relationship between them.

$(Y_{t+1},\ldots,Y_{t+k})|(F_{X,t},F_{Y,t}) \nsim Y_{t+1},\ldots,Y_{t+k})|(F_{X,t})$, where $\nsim$ denotes non-equivalence in distribution. $F_{X,t}$, $F_{Y,t}$ are the information sets that include past observations of X_t and Y_t, respectively, up to and including time t. We try to detect the existence of Granger causality for k=1, which is used extensively in the empirical literature. The null hypothesis is that $\{Y_t\}$ is conditionally independent of X_t , X_{t-1} ,… given Y_t , Y_{t-1} ,…, i.e that $\{X_t\}$ does not Granger cause $\{Y_t\}$.

To sum up, the linear Granger causality test examines the null hypothesis that the independent variable does not affect the dependent variable. This denotes that the estimated coefficients on the lagged values of the independent variable are equal to zero. If the null hypothesis is not true, then X_t linearly Granger causes Y_t and its own past values have significant predictive power for the current values of Y_t given past values of Y_t.

The linear Granger causality tests are performed within a VAR or VEC framework depending on the stationarity properties of the underlying series and linear combination thereof. If the series are non-stationary unit root processes and cointegrated, we use a Vector Error Correction (VEC) model, otherwise we use a VAR model in first-differences to test for causality.[37] The models are estimated in each subperiod using the Johansen (1995) maximum likelihood procedure, and are tested for autocorrelation by means of a Q-test (Ljung and Box, 1978). If there is autocorrelation, we increase the lag length of the VAR or VEC model.

In a VAR model, each variable of the system is determined based on the lagged values of the other variables, as well as on its own lagged values[38]. Thus, a VAR model for two stationary time series X_t and Y_t in first-differences can be written as follows:

$$\Delta Y_t = v_1 + \sum_{i=1}^{k} a_i \Delta Y_{t-i} + \sum_{i=1}^{k} b_i \Delta X_{t-i} + \varepsilon_{1t} \qquad \textbf{(1.1)}$$

[37] We check the residuals of the VAR or VEC model, and if we find outliers greater than 3 standard deviations, then we include a series of point dummy variables to capture specific abnormal events during the period under study. Our results are robust to a range of threshold values between 2.5 and 3.5 standard deviations.

[38] The Granger causality test is sensitive to lag structure. We specify the optimal lag order for every pair of variables, based on the well-known Akaike Information criterion (AIC) and then we examine the corresponding VAR or VEC model. The number of lags specifies the order of the VAR or VEC model. The application of the Granger causality test premises that all the variables will have the same lags.

$$\Delta X_t = v_2 + \sum_{i=1}^{k} c_i \Delta Y_{t-i} + \sum_{i=1}^{k} d_i \Delta X_{t-i} + \varepsilon_{2t} \quad \textbf{(1.2)}$$

where Δ denotes the first-differences operator, v is a vector of intercepts, k denotes the lag order of the VAR system, a, b, c, d are the regression coefficients and ε_{1t}, ε_{2t} denote the white noise error term with $E(\varepsilon_{it})=0$ (i=1,2) and $E(\varepsilon_{1t}\varepsilon_{2t})=0$.

So, Y_t Granger causes X_t if there is a $c_i \neq 0$, and X_t Granger causes Y_t if there is a $b_i \neq 0$. Also, there is a bidirectional causal relationship if $c_i \neq 0$ and $b_i \neq 0$ simultaneously.[39] This means that there is Granger causality, only if the lagged values of a variable in the estimated VAR model are statistically significant.[40]

We include an error correction term and we apply a VEC model[41] in order to test for linear Granger causality, if the series are non-stationary and cointegrated. A VEC model combines both the short and long-term characteristics of the variables under consideration, while it maintains the necessary property of stationarity. A bivariate VEC model specification is as follows:

$$\Delta Y_t = v_1 + \lambda_1 Z_{t-1} + \sum_{i=1}^{k} a_i \Delta Y_{t-i} + \sum_{i=1}^{k} b_i \Delta X_{t-i} + \varepsilon_{1t} \quad \textbf{(1.3)}$$

$$\Delta X_t = v_2 + \lambda_2 Z_{t-1} + \sum_{i=1}^{k} c_i \Delta Y_{t-i} + \sum_{i=1}^{k} d_i \Delta X_{t-i} + \varepsilon_{2t} \quad \textbf{(1.4)}$$

$$Z_{t-1} = Y_{t-1} - w_0 - w_1 X_{t-1} \quad \textbf{(1.5)}$$

where Δ denotes the first-differences, v is a vector of intercepts, k is the optimal lag length, a,b,c,d are the regression coefficients that capture the short-run dynamics, coefficient λ is the error correction term that denotes the speed of adjustment to the long-run equilibrium achieved through short-term adjustments for each series, Z_t is the OLS residual of the cointegrating equation, w denotes the long-run deviations, and ε_{1t},ε_{2t} denote the white noise error terms with $E(\varepsilon_{it})=0$ (i=1,2) and $E(\varepsilon_{1t}\varepsilon_{2t})=0$.

[39] In order to test the H_0 hypothesis, we use the F- statistic at the 5% significance level: $F = \frac{SSE^R - SSE^U/k}{SSE^U/F}$, where SSE^U: is the unrestricted sum of squared errors, SSE^R: is the restricted sum of squared errors, k: is the number of variables and F: is the number of degrees of freedom. The F-statistics are the Wald statistics for the hypothesis that the coefficients of all the lags of an endogenous variable are equal to zero.

[40] A disadvantage of the Granger causality test is its sensitivity to the lag structure. Different optimal number of lags are specified based on the chosen information criterion. The test is also affected by the frequency of the data and the techniques that are used to achieve stationarity.

[41] If the VAR model is of p-order, the VEC model should be of (p-1)-order.

We apply the linear Granger causality test on the raw data, as well as, on the VAR or VEC- filtered residuals in order to assess the incidence of causality between CDS innovations after first moment filtering.

1.4.2.2. Impulse response functions - Forecast error variance decomposition

We also carry out impulse response and variance decomposition analysis in cases in which we identify a causal relationship between the CDS series. This allows us to gain more insight into the magnitude and timing of the effects of a shock and its contribution to the variations of the endogenous variables in the current and future periods.[42] Impulse response plots depict the responses of sovereign CDS spreads, after a one standard deviation shock to the bank CDS spreads, and vice versa, over a 10-day horizon.

The shocks are quantified based on the standard deviations of the error terms. Because of the dynamic structure of a bivariate VAR or VEC model, a one standard deviation shock to the error term in the first equation is successively diffused and affects not only the first endogenous variable itself, but also, the other endogenous variable in the second equation of the model. For this reason, we use impulse response functions that specify the effects of a one standard deviation shock on current and future values of all the endogenous variables. In this way, we are able to specify the consequences of this disturbance.

After a shock to the error term of a VAR or VEC model, the error terms of the other equations of the system should remain constant and independent, in order to derive the impulse response functions. However, because the innovative shocks, occurring on different variables, are commonly correlated with each other, we cannot specify their independent effects. Thus, a shock will be a common component that cannot be determined, while its effect is not associated with a specific variable.[43] In order to overpass this malfunction, researchers implement the Cholesky decomposition method for the orthogonalization of the shocks.[44] Therefore, by using the orthogonal

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[42] If there are x variables in a system, x^2 impulse responses could be derived.

[43] In a bivariate VAR model the effects of the common component are usually attributed to the variable that comes first.

[44] See Lütkepohl and Reimers (1992); Lütkepohl (1993) and Hamilton (1994) for more details.

residuals to perform orthogonalized impulse response analysis, we are able to hypothesize that the shocks are contemporaneously uncorrelated.[45]

By applying the FEVD method, we analyze the forecast-error variance of an endogenous variable, in order to calculate the percentage effect of each of the orthogonal innovations on the mean square error (MSE) of the prediction (Hamilton, 1994). More specifically, FEVD contributes to the determination of the percentage variation of an endogenous variable that is attributed to its own shocks, in relation to the corresponding variation, due to shocks on the other endogenous variables of the system. Hence, we can find out whether the effect of a shock on the endogenous variables of a dynamic VAR or VEC model is significant and distinguish the relative influence of an innovative shock on each variable of the model.

1.4.2.3. Hsiao causality test

Aiming to figure out any potential variations in the pairwise linear causal relationships between sovereign and banking sector credit spreads of our sample, we employ the alternative linear causality test of Hsiao (1981). This is a modified version of the Granger test, allowing more flexibility in the choice of the dynamic lag structure. Hsiao's methodology (1981)[46] is based on the Granger's causality method (1969) and on the use of the Akaike's Final Prediction Error (FPE) criterion (1969).[47] More specifically, Hsiao considers that the hardest part in a multiple autoregressive process is the definition of the maximum number of lags. Thus, he proposes a method, which allows each variable to be inserted in the VAR model with a different lag, according to the minimum FPE criterion. This approach aims to reduce the number of the parameters under estimation, in order to balance the bias and inefficiency problems of the parameterized model. This option, according to Hsiao, is equivalent to applying an F-test with varying significance levels.

[45] The ordering of the variables is crucial for performing impulse response and variance decomposition analyses. In order to exceed the problem that arises because of the variable ordering, Pesaran and Shin (1998) used the Generalized impulse response functions. These functions overcome the limitation that simultaneous shocks on the variables should be uncorrelated.

[46] The same methodology is followed by Gomez-Puig and Sosvilla-Rivero (2013). They examine the Granger-causal relationships between the Eurozone countries, by using the 10-year government bonds for the period 1999-2010.

[47] According to Hsiao this methodology "is used to impose restrictions in order to capture empirical regularities which remain hidden to standard procedures".

We seek to ascertain the existence and the direction of causality before and after the announcement of the PSI program. The methodology is:

Supposing that Y_t and X_t are two stationary variables in levels (i.e. I(0)).

1. At first, we consider Y_t as a one-dimensional autoregressive process:

$$Y_t = \gamma_0 + \sum_{i=1}^{K} c_i Y_{t-i} + \varepsilon_t \qquad \textbf{(1.6)}$$

We calculate the FPEs, with the number of lags ranging from 1 to K. We choose the lag k, where 1≤k≤K, which implies the minimum FPE:[48,49]

$$FPE_Y(k, 0) = \frac{T+k+1}{T-k-1} * \frac{RSS}{T} \qquad \textbf{(1.7)}$$

2. Then, we consider Y_t as a controlled variable with lag equal to k, and X_t as a manipulated variable:

$$Y_t = \gamma_0 + \sum_{i=1}^{k} c_i Y_{t-i} + \sum_{j=1}^{L} p_j X_{t-j} + \varepsilon_t \qquad \textbf{(1.8)}$$

We re-calculate the FPEs of Y_t, changing the lags of X_t from 1 to L, and determine the lag l, where 1≤l≤L, which corresponds to the minimum value of FPE:

$$FPE_Y(k, l) = \frac{T+k+l+1}{T-k-l-1} * \frac{RSS}{T} \qquad \textbf{(1.9)}$$

3. Subsequently, we compare the FPE calculated in step 1, ($FPE_Y(k,0)$), with the corresponding FPE calculated in step 2, ($FPE_Y(k,l)$). If {$FPE_Y(k,0) > FPE_Y(k,l)$}, then the optimal model for the prediction of Y_t comes out by including k lags of Y_t and l of X_t. In this case, we conclude that X_t causes Y_t. Otherwise, if {$FPE_Y(k,0)0< FPE_Y(k,l)$}, then Y_t is calculated as a one-dimensional autoregressive process.

4. We repeat the process considering X_t as a controlled variable and Y_t as a manipulated one. If our variables Y_t and X_t have a unit root in levels, but, they are stationary in the first-differences (i.e. are integrated of order one, I(1)), we repeat the above procedure, in order to ascertain, whether there is a causal relationship between the ΔY_t and ΔX_t. If our variables are not cointegrated, we consider the following equations:

$$\Delta Y_t = \gamma_0 + \sum_{i=1}^{K} c_i \Delta Y_{t-i} + \varepsilon_t \qquad \textbf{(1.10)}$$

48 T: is the total number of the observations and RSS: is the Residual Sum of Squares of regression (1.6).

49 The FPEs are calculated on the assumption that the residuals are white noise.

$$\Delta Y_t = \gamma_0 + \sum_{i=1}^{K} c_i \Delta Y_{t-i} + \sum_{j=1}^{L} p_j \Delta X_{t-j} + \varepsilon_t \qquad \textbf{(1.11)}$$

Finally, if we find out that the under consideration time series are linked with a common stochastic trend (cointegrated), then we have to include an error correction term[50] in the equations (1.10) and (1.11):

$$\Delta Y_t = \gamma_0 + \beta ECT_{t-1} + \sum_{i=1}^{K} c_i \Delta Y_{t-i} + \varepsilon_t \qquad \textbf{(1.12)}$$

$$\Delta Y_t = \gamma_0 + \beta ECT_{t-1} + \sum_{i=1}^{K} c_i \Delta Y_{t-i} + \sum_{j=1}^{L} p_j \Delta X_{t-j} + \varepsilon_t \qquad \textbf{(1.13)}$$

Hence, with the minimum calculated FPEs, we determine the difference {FPE(k,0)-FPE(k,l)} for the time series in which there are causal relationships both before and after the notification of the PSI. Afterwards, we compare the size of this difference in each subperiod, in order to specify possible variations in the relative size of the interrelationships between sovereign and bank default risk, as a consequence of the PSI program. In this way, we assess the impact of this program on the CDS series of our sample.

1.4.3. Difference-in-difference model

We use a difference-in-difference model to assess the robustness of our empirical findings. For this purpose, we define a dummy variable, PSI, which takes the value of zero for the period before the PSI announcement, and is equal to one otherwise. The coefficient of the dummy variable measures the average short-term impact of a change in the explanatory variable on the response variable, after the notification of the intervention program that we are examining.

Specifically, we estimate the following equation:

$$\Delta Y_{it} = d_0 + d_1 PSI + d_2 INT + d_3 \Delta X_{it} + d_4 PSIZ_{t-1} + u_{it} \qquad \textbf{(1.14)}$$

where X and Y denote pairs of bank and sovereign CDS series, $INT = PSI * \Delta X_{it}$ and Z_t is the residual of the long-run equation $Y_{it} = \gamma_0 + \gamma_1 PSI + \gamma_2 X_{it} + u_{it}$, assuming that the two series cointegrate, otherwise we omit the error correction term. The coefficient of the interaction variable (INT) is the main parameter of interest since it reflects the change in the degree of interaction between the two CDS series.

We introduce the dummy variable PSI in the long-run equation, in order to shift the constant term from the cointegrating equation. Thus, the cointegrating equation

[50] It is about the error-correction term from the cointegrating equation $Y_t=\alpha+\beta X_t$.

changes, after the date of the announcement of the PSI program, once we have included the dummy variable in the long-term relationship. The coefficient γ_1 denotes the change of the constant term of the long-term relationship that we are considering. If it is positive, this implies that the constant term of the long-term equation changes in the value of γ_1. In this case, we conclude that both variables deviate further and further, and as a result the distance of the time series increases on average, after the announcement of the PSI. Now the equilibrium point Y_{it}, is on average higher for various values of X_{it}. The results are the opposite if γ_1 is negative. The coefficient d_4 declares the different speed of response due to the PSI program.

1.4.4. Nonlinear causality

The relationship between sovereign and bank CDS series varies during crisis periods, propagated by changes in the nexus between sovereigns and banks. This implies that nonlinear interlinkages may arise between sovereign and bank CDS, whereby the same change in fundamentals can have a much larger impact on spreads than was the case previously (see Delatte et al., 2014). Heterogeneous market assessments for a possible default may also induce nonlinearities in the causal relationships between sovereign and bank CDS series by amplifying sovereign risk. A linear model may fail to capture adequately a nonlinear structure in the relationship among different variables,[51] which may lead to erroneous conclusions regarding spillover causal effects among them (see Billio et al., 2012). For this reason, we turn next to study nonlinear dynamics in the relationship between the CDS series.

1.4.4.1. Nonlinear dependence BDS test

The BDS[52] test is a diagnostic nonlinear dependence test, aiming to find out if the data present nonlinearities, by examining for time based dependence in a series. In a general context, the BDS test is used to detect nonlinear structures of the data, while it assumes that the data are pure noise.[53] Thus, the null hypothesis is that the series are independent and identically distributed. According to Brock et al. (1996), for large

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[51] Nonlinearities are quite difficult to be specified through linear Granger causality tests (Brock et al., 1991).

[52] BDS: Brock, Dechert, Scheinkman and LeBaron (1996).

[53] The BDS test examines the series for the existence of linear and nonlinear dependence and/or deterministic chaos.

samples (n>500), the BDS statistic could be compared with the standard normal distribution, when the null hypothesis is true.

First we apply the univariate BDS test on the raw data. Furthermore, the test is implemented on the estimated residuals derived from the initial VAR or VEC model, in order to examine if they are independent and identically distributed (i.i.d.), (H_0). In this way, we are able to capture all the nonlinear dependence, by abstracting any remaining linear predictive power, and find out if the initial estimated model is adequate. If not, then the residuals will not be white noise and the BDS test should be statistically significant. In this case, the results of the BDS test imply that there are nonlinearities in the data and that it is necessary to extend our tests and explore for a nonlinear structure, in order to specify potential nonlinear spillover effects between the series. For this purpose, in the next subsection, we examine the D&P (2006) nonlinear Granger causality test.

1.4.4.2. Diks and Panchenko non-parametric Granger causality test

The D&P (2006) test is a non-parametric nonlinear causality test that allows to investigate for possible nonlinear components in the bidirectional relationship between two time series, in a more complex framework, without making any restrictive assumptions on their relationship. Under the null hypothesis there is no causality from X_t to Y_t for two strictly stationary time series (X_t, Y_t, $t \geq 1$), with finite lags l_X and l_Y, (l_X, l_Y, ≥ 1), formally stated as:

$$H_0: Y_{t+1} | (X_t^{l_X}, Y_t^{l_Y}) \sim Y_{t+1} | Y_t^{l_Y} \qquad \textbf{(1.15)}$$

where $X_t^{l_X} = (X_{t-l_X+1}, \ldots, X_t)$ and $Y_t^{l_Y} = (Y_{t-l_Y+1}, \ldots, Y_t)$ are lagged vectors. The null hypothesis is rejected, when current and past information of $X_t^{l_X}$ contributes to better prediction of Y_{t+1}.

D&P test for nonlinear causal spillover effects by considering the joint and marginal distributions of the (l_X+l_Y+1) dimensional stationary vector $W_t = \left(X_t^{l_X}, Y_t^{l_Y}, Z_t\right)$ where $Z_t = Y_{t+1}$, which under the null yield the following statistic:

$$q_g \equiv E\left[\left(\frac{f_{X,Y,Z}(X,Y,Z)}{f_Y(Y)} - \frac{f_{X,Y}(X,Y)}{f_Y(Y)}\frac{f_{Y,Z}(Y,Z)}{f_Y(Y)}\right) g(X,Y,Z)\right] = 0 \qquad \textbf{(1.16)}$$

Where g(X,Y,Z) is a positive weight function.[54] It is a conditional average of the dependence terms, where the null hypothesis is that q=0. For the weight function g(x,y,z)=f_Y^2(y), the above function is as follows:

$$q \equiv E\left[f_{(X,Y,Z)}(X,Y,Z)f_Y(Y) - f_{X,Y}(X,Y)f_{Y,Z}(Y,Z)\right] = 0 \qquad \textbf{(1.17)}$$

where $f_{(.)}$ denotes the associated joint and marginal densities. Defining a local square kernel density estimator $\hat{f}_W(w_i)$ of a d_W-variate random vector W at W_i such that: $\hat{f}_w(W_i) = \frac{(2e_n)^{-d_W}}{n-1}\sum_{j,j\neq i} I_{ij}^W$, where $I_{ij}^W = I(\|W_i - W_j\| < \varepsilon_n)$, I(.): is the indicator function, $\|.\|$ is the maximum norm and ε_n is the bandwidth, D&P show that the test statistic reduces to:

$$T_n(\varepsilon) = \frac{(n-1)}{n(n-2)}\sum_i\left(\hat{f}_{X,Y,Z}(X_i,Y_i,Z_i)\hat{f}_Y(Y_i) - \hat{f}_{X,Y}(X_i,Y_i)\hat{f}_{Y,Z}(Y_i,Z_i)\right) \qquad \textbf{(1.18)}$$

For $l_X = l_Y = 1$, and, if the bandwidth is calculated as $\varepsilon_n = Cn^{-\beta}$ (where n is the sample size, C>0, and $\beta \in \left(\frac{1}{4},\frac{1}{3}\right)$), D&P (2006) show that the distribution of the test statistic given by (1.18) converges to the standard normal distribution under the null given by:[55,56]

$$\sqrt{n}\,\frac{(T_n(\varepsilon_n)-q)}{S_n} \xrightarrow{d} N(0,1) \qquad \textbf{(1.19)}$$

where $\xrightarrow{d}$ denotes convergence in distribution and S_n(.) is an estimator of the asymptotic variance of T_n(.) (Diks and Panchenko, 2006, Bekiros and Diks, 2008). Therefore, the T_n( ) test statistic is asymptotically distributed as N(0,1), under certain conditions.

We apply the D&P (2006) causality test on the raw data. We also investigate for nonlinear causal relationships between the series by re-applying the D&P test to the estimated residual series that are obtained from the VAR or VEC models, in order to test if any observed causality is strictly nonlinear.

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54 D&P take the following weight function g(x,y,z)=f_Y^2(y) based on Monte Carlo simulations.

55 According to D&P (2006), when the local bias tends to zero at a rate of ε^2, then the optimal bandwidth that gives the T_n estimator with the smallest mean-squared-error is calculated based on $\varepsilon_n = Cn^{-2/7}$, where β=2/7 is the optimal rate. Since, unrealistically large values of the bandwidth may arise in small samples, based on the optimal value of C, D&P suggest the choice of bandwidth should be truncated by $\varepsilon_n = \max(Cn^{-2/7}, 1.5)$.

56 D&P (2006) contend that the H&J (1994) test could be asymptotically valid, if, for example, the bandwidth ε tends to zero, while the sample size increases.

1.4.4.3. A bivariate diagonal GARCH-BEKK (1,1) model

H&J (1994) and D&P (2005) among others, stress the importance of filtering out autoregressive conditional heteroskedasticity, when examining for potential nonlinear relationships between time series. Conditional heteroskedasticity could bias causality tests adversely affecting their power.[57,58] This is because volatility effects may in part or in whole account for nonlinear causal linkages between series. Thus, before applying the nonlinear Granger causality tests, it is important to examine for any remaining causal relationships between the CDS series after a second moment filtering.

This procedure is performed through a Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model.[59,60] There are different multivariate GARCH models, based on the approach that is followed for the parameterization of the conditional variance-covariance matrix.[61]

More specifically, in our study we apply a bivariate diagonal GARCH-BEKK (1,1) model, in order to measure the volatility spillovers and estimate the conditional correlations between the time series under examination. It also filters out any possible conditional volatility effects. This is possible by capturing the dynamics in the second moment of distribution that implies spurious causality between the series. Thus, a GARCH-BEKK model allows us to examine whether the volatility spillovers contribute to the existence of nonlinear causality.

A GARCH-BEKK (1,1) model is composed of a first-order autoregressive GARCH term and a first-order moving average ARCH term. The GARCH and the ARCH

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[57] D&P (2006) provide evidence that the results of the Baek and Brock (1992) test could be biased because of the existence of conditional heteroskedacity in the data.

[58] Forbes and Rigobon (2001) contend that correlation coefficient tests for contagion are biased upward during a crisis because of the presence of heteroskedasticity in market returns. The authors assume that there are no endogeneity and omitted variables issues in order to adjust the tests for this bias. After the adjustments for heteroskedasticity, they conclude that there was not contagion during specific crisis periods but only interdependence. These findings are in line with those of Pericoli and Sbracia (2003).

[59] The ARCH models were introduced by Engle (1982), while GARCH models by Bollerslev (1986) and Taylor (1986).

[60] Engle's ARCH model (1982) allows the conditional variance to be dependent on the error term of the previous period, while in a GARCH model the conditional variance depends on the past values of the volatility.

[61] Different multivariate GARCH models may lead to different results regarding the nonlinear causal relationships between the time series, because of the alternative restrictions on the variance-covariance structure of the model.

terms are, respectively, the variance and the volatility of the previous period. The latter is measured by the residuals of the mean equation. In a few words, a GARCH-BEKK model intends to control for conditional heteroskedasticity.

The Engle and Kroner (1995) GARCH-BEKK (p,q,K) model[62,63] is defined as:

$$H_t = C'C + \sum_{k=1}^{K}\sum_{j=1}^{q} A'_{ik}u_{t-i}u'_{t-i}A_{ik} + \sum_{k=1}^{K}\sum_{i=1}^{p} B'_{ik}H_{t-i}B_{ik} \qquad \textbf{(1.20)}$$

where C is an (N×N) upper triangular matrix, A is an (N×N) matrix of parameters, specifying the relation between the current conditional variance and lagged squared errors, B is an (N×N) matrix of parameters, with its diagonal elements specifying the impact of past conditional variances on current conditional variances, u_t is the vector of disturbances, while H_t is the conditional variance-covariance matrix of the error terms at time t which is assumed to be positive definite. The other elements of the matrices A and B specify the corresponding cross-market effects on the conditional variance and covariance. N is the number of variables in the model (N=2 in our model).

For simplicity, we assume that K=1, as per standard practice in empirical research. In this case, the BEKK (p,q,1) model is defined as:

$$H_t = C'C + \sum_{i=1}^{q} A'_i u_{t-i}u'_{t-i}A_i + \sum_{i=1}^{p} B'_i H_{t-i} B_i \qquad \textbf{(1.21)}$$

Thus, the GARCH-BEKK (1,1,1) model can be written as follows:

$$H_t = C'C + A'_1 u_{t-1}u'_{t-i}A_1 + B'_1 H_{t-1}B_1 \qquad \textbf{(1.22)}$$

In our case, where we have two variables -sovereign and bank CDS series- the parameterization of the BEKK (1,1,1) model is the following:

$$\begin{bmatrix} h_{11,t} & h_{12,t} \\ h_{21,t} & h_{22,t} \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix}' \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix} +$$

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}' \begin{bmatrix} \varepsilon_{1,t-1}^2 & \varepsilon_{1,t-1}\varepsilon_{2,t-1} \\ \varepsilon_{1,t-1}\varepsilon_{2,t-1} & \varepsilon_{2,t-1}^2 \end{bmatrix} \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} +$$

$$\begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}' \begin{bmatrix} h_{11,t-1} & h_{12,t-1} \\ h_{21,t-1} & h_{22,t-1} \end{bmatrix} \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} \qquad \textbf{(1.23)}$$

A major weakness of the BEKK model is the large number of parameters that must be estimated each time, depending on the dimension of the model. This complicates

[62] BEKK are the acronyms of Baba, Engle, Kroner and Kraft, who developed the model.

[63] There are three versions of the BEKK model: the symmetric, the asymmetric and the diagonal.

the estimation of its different coefficients. For this reason, we apply a diagonal GARCH-BEKK model[64], where the diagonal[65] matrices A and B are written as: $A=\begin{bmatrix} a_{11} & 0 \\ 0 & a_{22} \end{bmatrix}$, $B=\begin{bmatrix} b_{11} & 0 \\ 0 & b_{22} \end{bmatrix}$, where $a_{12}=a_{21}=0$ and $b_{12}=b_{21}=0$ are the imposed restrictions.

1.5. Empirical results

1.5.1. Bivariate stationarity and cointegration analysis

Before performing the stationarity and cointegration tests, as described in the previous section, we conduct the Chow breakpoint test. The results provide evidence that there are statistically significant variations in the estimated regression coefficients, and, as a consequence, they confirm the presence of a structural break at the date of the announcement of the PSI. Thus, we split the sample period in two subperiods. Afterwards, we examine the CDS series for the existence of stationarity in (log) levels in both subperiods, by applying the ADF, PP and KPSS unit root tests. We find that all the series are non-stationary unit root processes. By repeating this process, using this time, the first-differences of the log-CDS series, we infer that they are stationary. The unit root test results are presented in detail in Table A3 in the Appendix.

Table A4 in the Appendix presents the results of the Johansen's trace and maximum eigenvalue tests, after controlling for cointegration, in both subperiods. The lag length is specified according to the AIC. We assume that the cointegrating equations may be stationary around a non-zero mean. In the first subperiod, a significant cointegrating relationship is observed between the sovereign and banking sector CDS of Greece, Portugal, Spain and Ireland. We also find cointegration between Greek sovereign and Portuguese bank CDS, and between the weighted aggregate sovereign and bank CDS. In the second subperiod, we find cointegrating relationship between Greek, Spanish, Irish sovereign and bank CDS spreads, and between Greek sovereign and Irish bank CDS series. Moreover, we find that the sovereign CDS spreads of Greece and the unweighted bank CDS are cointegrated in both subperiods. We observe that for the

[64]GARCH-BEKK estimates $(p+q)KN^2+N(N+1)/2$ parameters, while a diagonal BEKK involves $(p+q)KN+N(N+1)/2$. In our model we assume that $p=q=K=1$.

[65] Silvennoinen and Teräsvirta (2008).

majority of CDS pairs there is no evidence of cointegrating relationship between them, in both subperiods. While this implies absence of a common trend or risk factor driving the series, there is still the possibility of temporal causal effects driven by nonlinear dynamics.

1.5.2. Results of linear causality tests

1.5.2.1. Linear Granger causality test

Based on the preceding test results, we are able to perform the linear Granger causality test in each subperiod and find out if the bank CDS spreads contribute to the prediction of the future prices of sovereign CDS spreads, and vice versa. We apply a VAR or VEC model for all the pairs of sovereign and bank credit spreads under consideration, in both subperiods, in order to carry out the linear Granger causality test and specify potential lead-lag causal relationships between them. Therefore, we run a VAR model in first-differences for the series that are not cointegrated and a VEC model in the log-level series, in case we find out the existence of cointegrating relationships.

Table 1.2 summarizes the results of the linear Granger causality test between banks and their sovereigns (Panel A), Greek sovereign CDS and bank CDS (Panel B), and aggregate CDS series (Panel C). In the first subperiod, before the PSI announcement, we find evidence of strong bidirectional causal relationships for the majority of the CDS pairs. Weak linear Granger causal effects run from the Greek and French bank CDS spreads to the sovereign CDS of Greece and from the sovereign CDS of Ireland to the Irish bank CDS spreads. Causality is also weak from the unweighted bank CDS spreads to the corresponding sovereign CDS. There is no evidence of linear causal effects from the Portuguese and Irish banks to their corresponding sovereign CDS.

Table 1.2: Linear Granger causality results

Dependent Variable	Independent Variable	Raw Data (p-value) Period 1	Raw Data (p-value) Period 2	Filtered Data (p-value) Period 1	Filtered Data (p-value) Period 2
Panel A					
GR	GR_Banks	0.0635*	0.1957	0.5018	0.4662
PT	PT_Banks	0.1350	0.1466	0.9393	0.7429
IT	IT_Banks	0.0243**	0.4990	0.9460	0.6582
SP	SP_Banks	0.0005***	0.0893*	0.6666	0.0906***
IR	IR_Banks	0.2925	0.0000***	0.7834	0.0356**
FR	FR_Banks	0.0005***	0.0000***	0.9809	0.3951
NL	NL_Banks	0.0064***	0.2599	0.4870	0.8787
DE	DE_Banks	0.0187**	0.3223	0.9394	0.3510
GR_Banks	GR	0.0000***	0.9638	0.8607	0.4431
PT_Banks	PT	0.0000***	0.0000***	0.6561	0.7249
IT_Banks	IT	0.0001***	0.0016***	0.7808	0.4521
SP_Banks	SP	0.0000***	0.0087***	0.9087	0.8495
IR_Banks	IR	0.0869*	0.0512*	0.9479	0.9350
FR_Banks	FR	0.0051***	0.0001***	0.8926	0.6021
NL_Banks	NL	0.0000***	0.0030***	0.6759	0.3832
DE_Banks	DE	0.0001***	0.5322	0.5516	0.9557
Panel B					
GR	PT_Banks	0.0012***	0.9843	0.6658	0.5374
GR	IT_Banks	0.0165**	0.1272	0.8064	0.9336
GR	SP_Banks	0.0006***	0.0093***	0.7520	0.9474
GR	IR_Banks	0.0246**	0.8240	0.2672	0.0757***
GR	FR_Banks	0.0609*	0.0058***	0.7860	0.7897
GR	NL_Banks	0.0072***	0.3585	0.6186	0.7165

GR	DE_Banks	0.0004***	0.3511	0.6306	0.7277
PT_Banks	GR	0.0000***	0.0115**	0.5039	0.1977
IT_Banks	GR	0.0000***	0.0344**	0.9201	0.5725
SP_Banks	GR	0.0002***	0.0841*	0.9512	0.7281
IR_Banks	GR	0.0054***	0.0028***	0.3679	0.8360
FR_Banks	GR	0.0000***	0.0235**	0.9924	0.7298
NL_Banks	GR	0.0000***	0.0287**	0.8188	0.9889
DE_Banks	GR	0.0150**	0.0131**	0.7063	0.6717
Panel C					
AllCountries (Weighted)	AllBanks (Weighted)	0.0312**	0.2185	0.8469	0.7642
AllCountries (Unweighted)	AllBanks (Unweighted)	0.0724*	0.1259	0.9178	0.5361
GR	AllBanks (Weighted)	0.0029***	0.0374**	0.8215	0.6332
GR	AllBanks (Unweighted)	0.0060***	0.3603	0.7860	0.6435
AllBanks (Weighted)	AllCountries (Weighted)	0.0001***	0.2800	0.7647	0.9725
AllBanks (Unweighted)	AllCountries (Unweighted)	0.0000***	0.1451	0.8828	0.9803
AllBanks (Weighted)	GR	0.0208**	0.0230**	0.7191	0.6558
AllBanks (Unweighted)	GR	0.0016***	0.3167	0.7468	0.6141

Note: The table reports the p-values of the Granger causality test, using a VAR or VEC model with raw data in Periods 1 and 2. The lag length of the models was determined by AIC. The null hypothesis is that there is no Granger causality between the sovereign and bank CDS spreads. *,**,*** denote rejection of the null hypothesis at the 10%, 5%, and 1% significance level, respectively.

Evidence of causality is weaker during the second subperiod, especially causality running from banks to their sovereigns (see Panel A) and from European banks to the Greek sovereign (see Panel B). However, there is no evidence of causality running from Greek sovereign CDS to bank CDS in the post-PSI period aside from some differences in the degree of statistical significance (see Panel B). In the majority of cases, causality is unidirectional in the second period. We find bidirectional causal linkages only between the sovereign and bank CDS spreads of Spain, Ireland and France. A rather surprising result in this period is the absence of causality between Greek sovereign and bank CDS. Causality is also weaker between the aggregate CDS series in the second subperiod (see Panel C).

We re-apply the linear Granger causality test to the VAR- or VEC- filtered residuals, in order to specify any possible remaining linear causality effects after first moment filtering. The residual series are stationary, whereas the Johansen test does not indicate any cointegration relationships between them.[66] Hence, we run a VAR model in raw data, so as to perform the pairwise linear causal analysis.[67] It is interesting that linear causality vanishes in most cases after VAR/VEC filtering in both subperiods, as shown in Table 1.2. We find only unilateral causal relationships running from the Irish bank CDS spreads to the sovereign CDS of Ireland and Greece, and from Spanish bank CDS to sovereign credit spreads of Spain in the second subperiod. Thus, we surmise nonlinear causality effects may be present albeit not captured by linear causality tests.

1.5.2.2. Impulse response functions - Forecast error variance decomposition

Complementary to the linear Granger causality test, we carry out impulse response and variance decomposition analysis, in order to investigate the full dynamics of the VAR or VEC model, only in cases where we identify a linear Granger causal relationship between the two time series. We use the VAR or VEC framework to estimate the impulse responses, depending on the existence of cointegration between each pair of variables.

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[66] The Ljung-Box Q-test on the residuals fails to reject the null hypothesis that there is no autocorrelation up to 10 lags.

[67] The optimal lag length is determined according to the AIC once again and is equal to one for each pair of variables, in both subperiods.

The impulse response graphs, as shown in Figures A1 and A2 in the Appendix, depict the progress of the response of sovereign CDS spreads, after a one standard deviation shock to the equation of the bank CDS spreads, and vice versa, over a 10-day horizon. The overall results are generally in agreement with the findings from the Granger causality tests. We find strong effects from sovereign CDS spreads to the corresponding bank CDS spreads, both in the period before and after the PSI program. In particular, we find stronger response of Greek, Irish, Portuguese and Spanish bank CDS to their sovereign CDS in the first subperiod, and Spanish bank CDS to sovereign CDS in the second subperiod. These findings indicate that the linkages are stronger in countries with weaker fiscal fundamentals supporting proposition P1b. Conversely, the impact of bank CDS on sovereign CDS is low, in most cases, especially in the second subperiod. The impact on bank CDS after a shock to the sovereign credit spreads of Greece is weaker during the second subperiod, corroborating proposition P2c. We also find lower persistence and magnitude in the effects of CDS shocks in the second subperiod.

Forecast error variance decomposition analysis shows that in the first subperiod, the largest fraction of variability in all sovereign CDS spreads is explained by their own shocks and only a small proportion by bank CDS spreads. On the contrary, we observe that sovereign CDS spreads account for a significant proportion of the variation in bank CDS. The results in the second subperiod are similar albeit not as strong. We do not find strong influence from the sovereign CDS spreads of Greece to the bank CDS spreads of the other countries – with the French bank CDS spreads being the only exception – consistent with proposition P2c.

1.5.2.3. Hsiao causality test

We proceed by examining for possible interrelation between sovereign and bank credit risk considering the Hsiao (1981) causality test. Table A5 in the Appendix provides the results of the Hsiao test, after calculating the FPEs, based on equations (1.10) and (1.11), in case the series are not cointegrated and on equations (1.12) and (1.13), if there is a long-run relationship between them. In the latter case, we include an error-correction term.[68] The results do not present significant deviations, in relation to the corresponding Granger causality test results.

During the first subperiod, we find significant bidirectional causality between the sovereign and bank CDS series. The only exception is the Portuguese and Irish bank CDS, which do not affect the CDS of the respective countries. Therefore, in a total of thirty-eight possible causal relations, causality is not detected in only two cases. In the second subperiod, we observe a limitation of the causal relations. More precisely, we do not find causality from the Greek, Portuguese, Italian, Spanish and Dutch bank CDS to their corresponding sovereign CDS series. Moreover, there is no interaction running from the sovereign CDS spreads of Greece and Germany to the Greek and German bank CDS, respectively. Also, the results show that there are no causal effects from the Portuguese bank CDS to the Greek sovereign CDS spreads. Concerning the aggregate CDS series, we do not observe any significant causal interrelations from the unweighted bank CDS to the Greek sovereign CDS spreads and from the unweighted sovereign CDS to the unweighted bank CDS series.

Furthermore, we calculate the difference of the minimum FPEs calculated in steps 1 and 2, FPE(k,0)-FPE(k,l), that capture causal changes between the two subperiods, The results are presented in Table 1.3. We infer that after the implementation of the PSI program, there is a reduction in the magnitude of the contagion effects between sovereign and bank default risk for the most pairs of the CDS series, since the level of differences between the FPEs have decreased in the second period. This renders support to the competing propositions P1c and P2c.

However, we find an increase in the causal effects running from the Italian, French and German bank CDS to the Greek sovereign CDS premiums and from the French bank CDS to the sovereign credit spreads of France.[69] Furthermore, the influence of the weighted and unweighted bank CDS to the corresponding sovereign CDS spreads strengthens during the second subperiod, as well as, the causal effects running from the weighted bank CDS to the sovereign CDS spreads of Greece.

[68] We specify the maximum number of lags K equal to 25. Hsiao (1981) sets this number equal to 15, but he uses quarterly data in his research.

[69] This is probably due to the fact that French private and government-led banks kept in their portfolios a large amount of Greek bonds during the implementation of the PSI, resulting in the strengthening of bank credit risk, and, its interaction with sovereign credit risk.

Table 1.3: Change of causality based on Hsiao causality test

Response variable	Control variable	1st period FPE (k,0) - FPE (k,l)	2nd period FPE (k,0) - FPE (k,l)	Causality
Panel A				
FR	FR_Banks	0.0000269	0.0000730	↑
DE	DE_Banks	0.0000279	0.0000002	↓
PT_Banks	PT	0.0000754	0.0000095	↓
IT_Banks	IT	0.0000573	0.0000081	↓
SP_Banks	SP	0.0000334	0.0000065	↓
IR_Banks	IR	0.0000252	0.0000019	↓
FR_Banks	FR	0.0000150	0.0000096	↓
NL_Banks	NL	0.0000183	0.0000049	↓
Panel B				
GR	IT_Banks	0.0000236	0.0000500	↑
GR	SP_Banks	0.0000296	0.0000012	↓
GR	IR_Banks	0.0000049	0.0000021	↓
GR	FR_Banks	0.0000085	0.0000854	↑
GR	NL_Banks	0.0000229	0.0000068	↓
GR	DE_Banks	0.0000296	0.0000458	↑
PT_Banks	GR	0.0000709	0.0000030	↓
IT_Banks	GR	0.0000702	0.0000038	↓
SP_Banks	GR	0.0000290	0.0000015	↓
IR_Banks	GR	0.0000181	0.0000054	↓
FR_Banks	GR	0.0000325	0.0000090	↓
NL_Banks	GR	0.0000277	0.0000001	↓
DE_Banks	GR	0.0000186	0.0000015	↓
Panel C				
AllCountries (Weighted)	AllBanks (Weighted)	0.0000049	0.0000134	↑
AllCountries (Unweighted)	AllBanks (Unweighted)	0.0000030	0.0000252	↑
GR	AllBanks (Weighted)	0.0000239	0.0000340	↑
AllBanks (Weighted)	AllCountries (Weighted)	0.0000154	0.0000000	↓
AllBanks (Weighted)	GR	0.0000202	0.0000004	↓
AllBanks (Unweighted)	GR	0.0000264	0.0000008	↓

Note: This table presents the changes in causality for the CDS time series, for which there is a causal relationship in both subperiods. Period 1 ranges from 1 Jan 2009 to 26 Oct 2011 and period 2 from 27 Oct 2011 to 30 May 2014. FPE is the final prediction error.

1.5.3. Difference-in-difference model

Afterwards, we examine for changes in the causal interrelationship between the CDS series through an alternative methodological approach in relation to the above subsections. Initially, we test for cointegration between the time series during the whole sample period. We find long-term equilibrium relationships between the sovereign and bank CDS series of Italy and Spain. Table 1.4 reports the estimation results after assessing the equation (1.14).[70] Consistent with our analysis thus far, it shows that in the majority of cases PSI has the effect of weakening the nexus between the CDS series, thereby providing further support to propositions P1c and P2c.

More specifically, by determining the coefficient of the variable INT (Interaction) for each relationship between the CDS series, we specify the effect of a change (by one unit) of bank CDS spreads -after the announcement of the PSI- to the respective sovereign CDS spreads, and vice versa. If the coefficient of INT is not statistically significant, we conclude that the effect of the independent variable to the corresponding equation that we examine has not changed. We note that in all cases, where the coefficient of the variable INT is statistically significant, there is a reduction in the influence of bank CDS spreads to the respective countries, and vice versa. The only exception concerns the effect of the Portuguese bank CDS to the government CDS spreads of Greece.

1.5.4. Results of nonlinear causality tests

1.5.4.1. Nonlinear dependence BDS test

We set the maximum correlation dimension equal to 6, which corresponds to the number of the consecutive data points. We also set the value of distance equal to 0.7. The null hypothesis of linear dependence can be rejected at the 1% significance level for almost all the univariate series (p-value=0). Thus, preliminary analysis confirms possible nonlinear dependence in the in the raw as well as VAR- or VEC- filtered series.

[70] In case that there are no cointegrating relationships between the CDS series, we estimate the following equation: $\Delta Y_{it} = d_0 + d_1 PSI + d_2 INT + d_3 \Delta X_{it} + u_{it}$.

Table 1.4: Difference-in-difference results

Response variable	Control variable	Coefficient of INT	Causality
Panel A			
GR	GR_Banks	-0.452319*** (p=0.0015)	↓
PT	PT_Banks	-0.451000*** (p=0.000)	↓
IT	IT_Banks	-0.068052 (p=0.2892)	-
SP	SP_Banks	-0.245120*** (p=0.0005)	↓
IR	IR_Banks	-0.099175 (p=0.2318)	-
FR	FR_Banks	0.002258 (p=0.9706)	-
NL	NL_Banks	-0.180817*** (p=0.0040)	↓
DE	DE_Banks	-0.219675*** (p=0.0064)	↓
GR_Banks	GR	-0.142951*** (p=0.000)	↓
PT_Banks	PT	-0.178193*** (p=0.0000)	↓
IT_Banks	IT	-0.007910 (p=0.8077)	-
SP_Banks	SP	-0.014501 (p=0.6128)	-
IR_Banks	IR	-0.212762*** (p=0.000)	↓
FR_Banks	FR	-0.151712*** (p=0.000)	↓
NL_Banks	NL	0.030557 (p=0.4818)	-
DE_Banks	DE	-0.100435*** (p=0.0008)	↓
Panel B			
GR	PT_Banks	0.604277*** (p=0.0000)	↑
GR	IT_Banks	-0.190138** (p=0.0384)	↓
GR	SP_Banks	-0.373821*** (p=0.0002)	↓
GR	IR_Banks	-0.336380*** (p=0.0054)	↓
GR	FR_Banks	-0.233092*** (p=0.0053)	↓

GR	NL_Banks	-0.260043** (p=0.0140)	↓
GR	DE_Banks	-0.266249*** (p=0.0032)	↓
PT_Banks	GR	-0.397791*** (p=0.0000)	↓
IT_Banks	GR	-0.357111*** (p=0.0000)	↓
SP_Banks	GR	-0.306020*** (p=0.0000)	↓
IR_Banks	GR	-0.239138*** (p=0.0000)	↓
FR_Banks	GR	-0.316442*** (p=0.0000)	↓
NL_Banks	GR	-0.195248*** (p=0.0000)	↓
DE_Banks	GR	-0.274261*** (p=0.0000)	↓
Panel C			
AllCountries (Weighted)	AllBanks (Weighted)	-0.222362*** (p=0.0035)	↓
AllCountries (Unweighted)	AllBanks (Unweighted)	-0.289925*** (p=0.3447)	↓
GR	AllBanks (Weighted)	-0.333059*** (p=0.0080)	↓
GR	AllBanks (Unweighted)	-0.367981** (p=0.0282)	↓
AllBanks (Weighted)	AllCountries (Weighted)	-0.246111*** (p=0.0000)	↓
AllBanks (Unweighted)	AllCountries (Unweighted)	-0.372851*** (p=0.0000)	↓
AllBanks (Weighted)	GR	-0.277710*** (p=0.0000)	↓
AllBanks (Unweighted)	GR	-0.248994*** (p=0.000)	↓

Note: INT is the PSI interaction variable with the corresponding CDS. Numbers in parentheses are p-values. *, **, *** denote statistical significance at the 10%, 5%, and 1% level, respectively.

1.5.4.2. Diks and Panchenko non-parametric Granger causality test

Based on the BDS test results,[71] we apply the non-parametric D&P (2006) nonlinear Granger causality test, in order to investigate for nonlinear causal dynamic interactions between the sovereign and bank CDS series. We present the results after performing the D&P test to the log-differenced series, and, to the VAR- or VEC-filtered residuals. Table 1.5 presents the results of the D&P nonlinear causality test for the log-differenced CDS series with the number of lags set at $l_x=l_y=1,2,3,4,5,6$.[72] In the first subperiod, there is evidence of strong and persistent bidirectional nonlinear causal effects for the majority of the pairs of CDS series. There is no evidence of causality between the sovereign and bank CDS spreads of Ireland (see Panel A). Moreover, there are no nonlinear causal effects between the Irish bank CDS spreads and sovereign credit spreads of Greece (see Panel B). We also do not detect nonlinear causality running from the unweighted sovereign CDS spreads to the corresponding bank CDS, and from the Greek sovereign CDS to the unweighted bank CDS spreads of our sample (see Panel C).

In the second subperiod, we observe weaker nonlinear causal relationships albeit their number is greater than those reported in Table 1.2 above. There is also stronger evidence of bidirectional causality in comparison to the results of Table 1.2, especially in the relationship between Greek sovereign CDS and European bank CDS (see Panel B). More precisely, we do not find nonlinear interrelationships between the sovereign and bank CDS spreads of Ireland, whereas the Greek, Portuguese and German bank CDS do not have significant nonlinear causal effects on the respective sovereign CDS spreads (see Panel A). Also, there are no causal effects running from the bank credit spreads of Ireland, the Netherlands and Germany to the Greek sovereign credit spreads, while the latter do not influence the bank CDS spreads of Italy and the Netherlands. Contrary to the results of the first subperiod, in the second one, the lag values of sovereign CDS spreads of Greece have significant explanatory power for predicting the French and German bank CDS spreads (see Panel B).

[71] According to D&P (2006) "the test statistic can be interpreted as an average over local BDS statistics".

[72] Following Bekiros and Diks (2008), we set the constant term C* equal to 7.5. We set the optimal bandwidths at 1.14 for the first period and 1.17 for the second period. For robustness, we perform the D&P test for different bandwidths with no noticeable effects on the results.

Table 1.5: Nonlinear D&P Granger causality results in raw return data

Dependent Variable	Independent Variable	l=1	l=2	l=3	l=4	l=5	l=6
		Period 1					
Panel A							
GR	GR_Banks	0.000***	0.002***	0.009***	0.008***	0.011**	0.038**
PT	PT_Banks	0.000***	0.000***	0.009***	0.038**	0.037**	0.104
IT	IT_Banks	0.005***	0.034**	0.010**	0.027**	0.060*	0.154
SP	SP_Banks	0.013**	0.010**	0.006***	0.035**	0.299	0.397
IR	IR_Banks	0.463	0.174	0.708	0.866	0.722	0.840
FR	FR_Banks	0.028**	0.010**	0.021**	0.023**	0.022**	0.043**
NL	NL_Banks	0.010**	0.021**	0.053*	0.077*	0.121	0.081*
DE	DE_Banks	0.010**	0.000***	0.005***	0.034**	0.050*	0.045**
GR_Banks	GR	0.006***	0.113	0.523	0.570	0.948	0.972
PT_Banks	PT	0.002***	0.000***	0.001***	0.004***	0.023**	0.049**
IT_Banks	IT	0.055*	0.073*	0.025**	0.085*	0.158	0.381
SP_Banks	SP	0.005***	0.000***	0.001***	0.009***	0.028**	0.059*
IR_Banks	IR	0.619	0.495	0.476	0.524	0.799	0.791
FR_Banks	FR	0.001***	0.001***	0.035**	0.075*	0.209	0.182
NL_Banks	NL	0.055*	0.052**	0.292	0.475	0.525	0.740
DE_Banks	DE	0.003***	0.003***	0.001***	0.005***	0.010**	0.150
Panel B							
GR	PT_Banks	0.000***	0.001***	0.009***	0.030**	0.039**	0.074*
GR	IT_Banks	0.001***	0.001***	0.006***	0.017**	0.043**	0.096*
GR	SP_Banks	0.019**	0.040**	0.196	0.315	0.345	0.246
GR	IR_Banks	0.344	0.191	0.683	0.571	0.500	0.527
GR	FR_Banks	0.013**	0.018**	0.060*	0.069*	0.051*	0.180
GR	NL_Banks	0.000***	0.001***	0.005***	0.005***	0.017**	0.022**
GR	DE_Banks	0.030**	0.006***	0.045**	0.246	0.257	0.384
PT_Banks	GR	0.048**	0.041**	0.089*	0.073*	0.433	0.754
IT_Banks	GR	0.021**	0.011**	0.010**	0.037**	0.283	0.418
SP_Banks	GR	0.076*	0.047***	0.018**	0.023**	0.102	0.236
IR_Banks	GR	0.921	0.499	0.570	0.716	0.794	0.839
FR_Banks	GR	0.086*	0.071*	0.230	0.249	0.419	0.271
NL_Banks	GR	0.110	0.154	0.115	0.068*	0.147	0.281
DE_Banks	GR	0.106	0.064*	0.224	0.150	0.395	0.368
Panel C							
AllCountries (Weighted)	AllBanks (Weighted)	0.000***	0.003***	0.006***	0.026**	0.098*	0.190
AllCountries (Unweighted)	AllBanks (Unweighted)	0.031**	0.051*	0.157	0.240	0.243	0.366
GR	AllBanks (Weighted)	0.006***	0.009***	0.044**	0.085*	0.112	0.297
GR	AllBanks (Unweighted)	0.018**	0.020**	0.106	0.091	0.233	0.410
AllBanks (Weighted)	AllCountries (Weighted)	0.067*	0.014**	0.034**	0.045	0.261	0.234
AllBanks (Unweighted)	AllCountries (Unweighted)	0.792	0.597	0.401	0.373	0.728	0.774
AllBanks (Weighted)	GR	0.179	0.061*	0.194	0.287	0.520	0.597
AllBanks (Unweighted)	GR	0.488	0.231	0.367	0.537	0.787	0.887

		Period 2					
Dependent Variable	Independent Variable	l=1	l=2	l=3	l=4	l=5	l=6
Panel A							
GR	GR_Banks	0.2383	0.2798	0.1905	0.1391	0.1401	0.1543
PT	PT_Banks	0.5467	0.8285	0.9686	0.7497	0.6264	0.5632
IT	IT_Banks	0.47068	0.0309**	0.0170**	0.0464**	0.1093	0.1730
SP	SP_Banks	0.0127**	0.0537*	0.1411	0.2737	0.5438	0.6041
IR	IR_Banks	0.5793	0.1843	0.3133	0.2333	0.1826	0.2020
FR	FR_Banks	0.0027***	0.0025***	0.0148**	0.0783*	0.0877*	0.2091
NL	NL_Banks	0.0215**	0.0820*	0.0994*	0.2425	0.4568	0.3191
DE	DE_Banks	0.1310	0.1161	0.3063	0.4271	0.3197	0.4601
GR_Banks	GR	0.3448	0.1078	0.3326	0.1091	0.0531*	0.0665*
PT_Banks	PT	0.0216**	0.2118	0.3685	0.6087	0.4171	0.4455
IT_Banks	IT	0.0154**	0.1361	0.1794	0.4643	0.1696	0.2199
SP_Banks	SP	0.0404**	0.1295	0.2464	0.2973	0.2031	0.2841
IR_Banks	IR	0.9561	0.9294	0.9644	0.2573	0.3309	0.4757
FR_Banks	FR	0.0005***	0.0101**	0.0982*	0.0457**	0.1061	0.6556
NL_Banks	NL	0.9357	0.5441	0.3034	0.8148	0.8073	0.8310
DE_Banks	DE	0.0366**	0.3273	0.6935	0.1706	0.0885*	0.0340**
Panel B							
GR	PT_Banks	0.0668*	0.1942	0.4256	0.6378	0.3809	0.3515
GR	IT_Banks	0.0845*	0.1311	0.1481	0 .0817*	0.1358	0.1941
GR	SP_Banks	0.0887*	0.1679	0.0493**	0.1016	0.1648	0.1463
GR	IR_Banks	0.1469	0.6871	0.9849	0.9538	0.5464	0.5288
GR	FR_Banks	0.0330**	0.0051***	0.0170**	0.0187**	0.0136**	0.0747*
GR	NL_Banks	0.4208	0.6325	0.4486	0.4403	0.4578	0.5796
GR	DE_Banks	0.3041	0.2323	0.5456	0.5183	0.7978	0.8797
PT_Banks	GR	0.0708*	0.1670	0.6344	0.8280	0.8556	0.8295
IT_Banks	GR	0.1981	0.3395	0.2261	0.4571	0.5312	0.7230
SP_Banks	GR	0.0257**	0.1531	0.0656*	0.1545	0.1450	0.4425
IR_Banks	GR	0.7980	0.3800	0.2301	0.0949*	0.1227	0.1826
FR_Banks	GR	0.001***	0.0008***	0.0012***	0.0162**	0.0103**	0.0220**
NL_Banks	GR	0.6542	0.9192	0.8781	0.8957	0.5453	0.7305
DE_Banks	GR	0.0112**	0.0883*	0.2000	0.3080	0.2273	0.4764
Panel C							
AllCountries (Weighted)	AllBanks (Weighted)	0.0427**	0.0693*	0.0646	0.0865*	0.3120	0.6213
AllCountries (Unweighted)	AllBanks (Unweighted)	0.0328**	0.0843*	0.1078	0.3647	0.2163	0.2688
GR	AllBanks (Weighted)	0.0619*	0.0755*	0.0539*	0.0312**	0.0763*	0.3258
GR	AllBanks (Unweighted)	0.5435	0.2443	0.5266	0.3571	0.2856	0.5287
AllBanks (Weighted)	AllCountries (Weighted)	0.0195**	0.0343**	0.0056***	0.0181**	0.0637*	0.1315
AllBanks (Unweighted)	AllCountries (Unweighted)	0.0498**	0.0254**	0.0160**	0.0284**	0.0590*	0.0101**
AllBanks (Weighted)	GR	0.0197**	0.0234**	0.0268**	0.0793*	0.0468**	0.1823
AllBanks (Unweighted)	GR	0.5274	0.1953	0.1610	0.1780	0.1260	0.1579

Note: The table reports p-values of the nonlinear D&P Granger causality test on the raw return data for lags l_X=l_Y=1,2,3,4,5,6. We test the null hypothesis that there is no Granger causality between the sovereign and bank CDS spreads. *,**,*** denote rejection of the null hypothesis at the 10%, 5%, and 1% significance level, respectively.

There are no causal interlinkages between the unweighted bank CDS spreads and the Greek sovereign CDS spreads (see Panel C). We notice that the causal effects running from banks to sovereigns are significantly restricted in the second subperiod, while the inverse effects are stable in both subperiods. Conclusively, we observe that there are many nonlinearities in the causal relationships between sovereign and bank CDS spreads that cannot be captured in a linear framework.

Subsequently, we also examine for nonlinear causal interconnections between the CDS series by employing the D&P (2006) test to the estimated residual series[73] that are obtained from the initial VAR or VEC models. This allows us to eliminate any potential linear causal dynamics and possible estimation bias[74] and to identify whether the effects shown in Table 1.5 above are strictly driven by nonlinear causality. These results are reported in Table 1.6. We observe a decrease in the number of causal relationships after first moment filtering. The change is more notable for the CDS between banks and their sovereigns (see Panel A) in the first subperiod, and between the sovereign CDS of Greece and European bank CDS in the second period (see Panel B). We surmise these findings are consistent with proposition P3c since they suggest that nonlinear dynamics are less likely to dominate the nexus between sovereign and bank CDS spreads in the second subperiod.

Analytically, in the first subperiod, in addition to the corresponding results in the previous step, we do not find strong causal effects running from the Italian bank CDS spreads to the corresponding sovereign CDS (see Panel A). The Spanish, French, and German bank CDS do not Granger cause the Greek sovereign CDS spreads, while the latter have no predictive power on the Portuguese, French and Dutch bank CDS spreads (see Panel B). We also notice that there are no interactions between the sovereign CDS spreads of Greece and the weighted and unweighted bank CDS spreads.

[73] We use raw data, since all the residual series are found to be stationary in levels after performing PP, ADF, and KPSS unit root tests.

[74] According to Baek and Brock (1992), the residuals lose their linear predictive power after first moment filtering, and if there is a sign of causality, this will be attributed to nonlinear predictive power.

Table 1.6: Nonlinear D&P Granger causality results for VAR- or VEC- filtered data

		Period 1					
Dependent Variable	Independent Variable	l=1	l=2	l=3	l=4	l=5	l=6
Panel A							
GR	GR_Banks	0.013**	0.077*	0.050*	0.059*	0.099*	0.218
PT	PT_Banks	0.002***	0.002***	0.039**	0.032**	0.056**	0.023**
IT	IT_Banks	0.071*	0.276	0.125	0.247	0.383	0.560
SP	SP_Banks	0.018**	0.027**	0.045**	0.037**	0.262	0.406
IR	IR_Banks	0.907	0.560	0.985	0.971	0.950	0.823
FR	FR_Banks	0.129	0.010**	0.041**	0.028**	0.050*	0.070*
NL	NL_Banks	0.049**	0.137	0.067*	0.101	0.154	0.141
DE	DE_Banks	0.100	0.002***	0.002***	0.004***	0.018**	0.019**
GR_Banks	GR	0.004***	0.030**	0.261	0.297	0.703	0.733
PT_Banks	PT	0.150	0.025**	0.007***	0.010**	0.008***	0.027**
IT_Banks	IT	0.145	0.253	0.333	0.498	0.570	0.639
SP_Banks	SP	0.088*	0.051*	0.077*	0.112	0.061*	0.147
IR_Banks	IR	0.937	0.741	0.858	0.746	0.780	0.606
FR_Banks	FR	0.053*	0.018**	0.055*	0.066*	0.069*	0.190
NL_Banks	NL	0.380	0.518	0.266	0.488	0.475	0.573
DE_Banks	DE	0.016**	0.017**	0.011**	0.104	0.120	0.441
Panel B							
GR	PT_Banks	0.048**	0.144	0.087*	0.068*	0.209	0.265
GR	IT_Banks	0.197	0.041**	0.019**	0.032**	0.044**	0.099*
GR	SP_Banks	0.107	0.242	0.424	0.463	0.544	0.446
GR	IR_Banks	0.754	0.483	0.853	0.755	0.175	0.138
GR	FR_Banks	0.103	0.163	0.114	0.151	0.151	0.338
GR	NL_Banks	0.263	0.051*	0.048**	0.037**	0.059*	0.029**
GR	DE_Banks	0.308	0.296	0.543	0.458	0.654	0.519
PT_Banks	GR	0.155	0.213	0.126	0.140	0.549	0.621
IT_Banks	GR	0.052***	0.113	0.121	0.218	0.351	0.435
SP_Banks	GR	0.055***	0.145	0.081*	0.053*	0.116	0.196
IR_Banks	GR	0.751	0.865	0.927	0.909	0.927	0.943
FR_Banks	GR	0.111	0.668	0.768	0.749	0.602	0.596
NL_Banks	GR	0.296	0.159	0.163	0.226	0.262	0.453
DE_Banks	GR	0.059***	0.583	0.625	0.329	0.397	0.520
Panel C							
AllCountries (Weighted)	AllBanks (Weighted)	0.051*	0.231	0.347	0.340	0.364	0.333
AllCountries (Unweighted)	AllBanks (Unweighted)	0.075*	0.190	0.567	0.352	0.339	0.453
GR	AllBanks (Weighted)	0.262	0.232	0.488	0.338	0.492	0.695
GR	AllBanks (Unweighted)	0.230	0.251	0.735	0.344	0.521	0.565
AllBanks (Weighted)	AllCountries (Weighted)	0.460	0.098*	0.246	0.185	0.293	0.165
AllBanks (Unweighted)	AllCountries (Unweighted)	0.990	0.657	0.592	0.540	0.951	0.937
AllBanks (Weighted)	GR	0.260	0.205	0.254	0.263	0.424	0.583
AllBanks (Unweighted)	GR	0.657	0.333	0.359	0.329	0.581	0.794

Dependent Variable	Independent Variable	l=1	l=2	l=3	l=4	l=5	l=6
		Period 2					
Panel A							
GR	GR_Banks	0.351	0.685	0.723	0.790	0.616	0.412
PT	PT_Banks	0.982	0.961	0.988	0.667	0.631	0.651
IT	IT_Banks	0.904	0.363	0.172	0.260	0.669	0.698
SP	SP_Banks	0.635	0.338	0.201	0.494	0.631	0.646
IR	IR_Banks	0.733	0.501	0.280	0.412	0.435	0.634
FR	FR_Banks	0.251	0.084*	0.083*	0.167	0.251	0.519
NL	NL_Banks	0.058*	0.109	0.097*	0.216	0.266	0.288
DE	DE_Banks	0.095*	0.025**	0.040**	0.223	0.324	0.420
GR_Banks	GR	0.337	0.102	0.399	0.603	0.405	0.280
PT_Banks	PT	0.119	0.414	0.581	0.512	0.555	0.532
IT_Banks	IT	0.075*	0.088*	0.569	0.855	0.493	0.367
SP_Banks	SP	0.135	0.195	0.680	0.778	0.631	0.726
IR_Banks	IR	0.349	0.509	0.439	0.212	0.133	0.372
FR_Banks	FR	0.147	0.221	0.177	0.131	0.473	0.625
NL_Banks	NL	0.816	0.670	0.351	0.903	0.288	0.876
DE_Banks	DE	0.018**	0.388	0.518	0.315	0.034**	0.032**
Panel B							
GR	PT_Banks	0.261	0.401	0.643	0.454	0.348	0.506
GR	IT_Banks	0.124	0.033**	0.063*	0.058*	0.063*	0.105
GR	SP_Banks	0.008***	0.005***	0.002*	0.030**	0.040**	0.082*
GR	IR_Banks	0.368	0.298	0.872	0.870	0.907	0.828
GR	FR_Banks	0.006***	0.005***	0.044**	0.022**	0.053*	0.070*
GR	NL_Banks	0.680	0.400	0.493	0.727	0.703	0.783
GR	DE_Banks	0.308	0.158	0.324	0.536	0.646	0.835
PT_Banks	GR	0.257	0.600	0.818	0.737	0.571	0.347
IT_Banks	GR	0.304	0.573	0.472	0.724	0.893	0.957
SP_Banks	GR	0.188	0.038**	0.023**	0.084	0.110	0.280
IR_Banks	GR	0.533	0.365	0.553	0.216	0.063*	0.174
FR_Banks	GR	0.004*	0.060*	0.022**	0.088*	0.099*	0.093*
NL_Banks	GR	0.471	0.390	0.225	0.265	0.266	0.339
DE_Banks	GR	0.056*	0.206	0.324	0.578	0.548	0.600
Panel C							
AllCountries (Weighted)	AllBanks (Weighted)	0.089*	0.152	0.072*	0.310	0.796	0.844
AllCountries (Unweighted)	AllBanks (Unweighted)	0.084*	0.156	0.222	0.612	0.627	0.754
GR	AllBanks (Weighted)	0.106	0.069*	0.070*	0.227	0.429	0.751
GR	AllBanks (Unweighted)	0.287	0.375	0.448	0.609	0.531	0.465
AllBanks (Weighted)	AllCountries (Weighted)	0.166	0.234	0.116	0.199	0.420	0.703
AllBanks (Unweighted)	AllCountries (Unweighted)	0.055*	0.062*	0.041**	0.037**	0.051*	0.027**
AllBanks (Weighted)	GR	0.139	0.699	0.240	0.346	0.407	0.346
AllBanks (Unweighted)	GR	0.727	0.913	0.602	0.587	0.534	0.607

Note: The table reports p-values of the nonlinear D&P Granger causality test on the VAR- or VEC- filtered data for lags $l_X=l_Y=1,2,3,4,5,6$. We test the null hypothesis that there is no Granger causality between the sovereign and bank CDS spreads. *,**,*** denote rejection of the null hypothesis at the 10%, 5%, and 1% significance level, respectively.

In the pairs of CDS series where the D&P test results verify the existence of nonlinear causal effects, we observe that the duration and the magnitude of these effects have been reduced. Concerning the causal effects between the weighted sovereign and bank CDS spreads, the findings are in the same direction.

The results indicate the presence of weak nonlinear causal interconnectedness, in the second subperiod. We find nonlinear bidirectional causal relationships between the sovereign and bank CDS spreads of Germany. There are persistent one-sided causal relationships derived from the French and Dutch bank CDS to the corresponding sovereign CDS and from the Italian sovereign CDS spreads to the bank CDS (see Panel A). Additionally, we identify nonlinear interlinkages between the Greek sovereign and French bank CDS spreads and between the Greek sovereign and Spanish bank CDS. There are unilateral weak causal relationships running from the Italian bank CDS to the Greek sovereign CDS spreads and from the Greek sovereign CDS to the Irish and German bank CDS (see Panel B). Also, the weighted bank CDS have weak causal effects on the weighted sovereign CDS spreads and on the Greek sovereign CDS, whereas there is a bidirectional relationship between the unweighted sovereign and bank CDS spreads (see Panel C).

1.5.5. GARCH results

ARCH tests on the residual series that arise from the initial VAR or VEC models, indicate the existence of conditional heteroskedasticity in the CDS series. Before performing the nonlinear Granger causality tests, it is necessary to address possible heteroskedastic structures that distort the causality test results. This happens because they contribute to the over-rejection of the null hypothesis. Our aim is to capture the volatility spillover effects between sovereign and bank CDS series, in both subperiods. For this purpose, we use the standardized GARCH-filtered residuals[75] that arise after second moment filtering and we re-run the causality tests in each subperiod.

The results of the D&P nonlinear causality test after GARCH-BEKK filtering are shown in Table 1.7.[76] The persistence and significance of nonlinear causal

[75] We use the conditional covariance matrix H_t to whiten the VAR or VEC residuals via the matrix transformation $z_t=H_t^{-1/2}u_t$.

[76] There is a possibility of higher-order conditional moments between the CDS series, if nonlinear causal effects persist after GARCH-BEKK filtering.

relationships are lower than those reported previously. Some of the notable differences are as follows: There is no longer evidence of bidirectional causality between Spanish, French and German bank and sovereign CDS after GARCH-BEKK filtering in the first subperiod albeit unidirectional causality from German and Spanish bank CDS to their sovereign CDS is maintained. There is also no evidence of causality running from Italian bank CDS to sovereign CDS, and from Greek sovereign CDS to German and Italian bank CDS. In the second subperiod, we find no evidence of unidirectional causality from Dutch and French bank CDS to their sovereign CDS, and from Greek and Italian sovereign CDS to the corresponding bank CDS, after GARCH-BEKK filtering. This reduction in the causal relationships corroborates the presence of volatility spillover effects as postulated by proposition P3b.

More specifically, in the first subperiod, we find persistent causal effects from Greek, Portuguese and German bank CDS to the corresponding sovereign CDS spreads. In addition, there are shorter duration unilateral causal relationships from Spanish and Dutch bank CDS spreads to the sovereign CDS of Spain and the Netherlands (see Panel A). There is also weak evidence of causality running from Greek sovereign CDS spreads to Greek, Portuguese, Spanish, German and unweighted bank CDS spreads (see Panels B and C). In the second subperiod, we find evidence for the existence of bidirectional causal interlinkages between German sovereign and bank CDS spreads (see Panel A). Moreover, there are strong interrelationships between Greek sovereign and Spanish bank CDS, as well as between Greek sovereign and Portuguese bank CDS. There are also causal effects from French and German bank CDS to the sovereign CDS spreads of Greece, and persistent causal effects from Italian bank CDS spreads to Greek sovereign CDS (see Panel B). The sovereign credit spreads of Greece have weak causal effects on the weighted bank CDS, while the unweighted sovereign CDS spreads have significant explanatory power for predicting the respective bank CDS (see Panel C).

Overall the results of Table 1.7 show that volatility effects and spillovers are occurring mainly in Panel A, namely in the CDS spreads between banks and their sovereigns. On the other hand, the results in Panels B and C indicate that nonlinear causal effects persist after GARCH filtering in both periods, suggesting that volatility spillovers are less likely to induce nonlinear causality.

Table 1.7: Nonlinear D&P Granger causality results for GARCH-BEKK- filtered data

		Period 1					
Dependent Variable	Independent Variable	l=1	l=2	l=3	l=4	l=5	l=6
Panel A							
GR	GR_Banks	0.045**	0.072*	0.039**	0.020**	0.017**	0.049**
PT	PT_Banks	0.000***	0.006***	0.057*	0.126	0.310	0.099*
IT	IT_Banks	0.132	0.265	0.252	0.318	0.324	0.396
SP	SP_Banks	0.032**	0.041**	0.073*	0.273	0.695	0.671
IR	IR_Banks	0.654	0.452	0.943	0.793	0.833	0.853
FR	FR_Banks	0.178	0.143	0.192	0.396	0.385	0.537
NL	NL_Banks	0.055*	0.106	0.046**	0.107	0.184	0.218
DE	DE_Banks	0.469	0.016**	0.020**	0.044**	0.041**	0.065*
GR_Banks	GR	0.028**	0.128	0.416	0.349	0.725	0.778
PT_Banks	PT	0.280	0.150	0.099*	0.064*	0.137	0.252
IT_Banks	IT	0.477	0.399	0.612	0.816	0.582	0.516
SP_Banks	SP	0.197	0.206	0.153	0.469	0.120	0.196
IR_Banks	IR	0.749	0.449	0.392	0.245	0.366	0.448
FR_Banks	FR	0.749	0.428	0.560	0.813	0.706	0.544
NL_Banks	NL	0.470	0.682	0.488	0.777	0.842	0.897
DE_Banks	DE	0.220	0.177	0.087*	0.215	0.467	0.591
Panel B							
GR	PT_Banks	0.144	0.569	0.241	0.087*	0.261	0.406
GR	IT_Banks	0.708	0.200	0.031**	0.118	0.253	0.506
GR	SP_Banks	0.297	0.218	0.305	0.387	0.547	0.551
GR	IR_Banks	0.679	0.643	0.866	0.756	0.298	0.105
GR	FR_Banks	0.202	0.232	0.130	0.264	0.527	0.794
GR	NL_Banks	0.824	0.269	0.141	0.102	0.060*	0.064*
GR	DE_Banks	0.650	0.332	0.713	0.758	0.977	0.931
PT_Banks	GR	0.046**	0.360	0.147	0.145	0.346	0.547
IT_Banks	GR	0.249	0.408	0.632	0.674	0.294	0.238
SP_Banks	GR	0.057*	0.165	0.096	0.110	0.161	0.234
IR_Banks	GR	0.851	0.655	0.515	0.368	0.615	0.527
FR_Banks	GR	0.166	0.673	0.612	0.679	0.529	0.375
NL_Banks	GR	0.199	0.217	0.575	0.648	0.658	0.495
DE_Banks	GR	0.042**	0.122	0.122	0.066*	0.163	0.051*
Panel C							
AllCountries (Weighted)	AllBanks (Weighted)	0.048**	0.110	0.480	0.927	0.747	0.658
AllCountries (Unweighted)	AllBanks (Unweighted)	0.142	0.257	0.665	0.257	0.173	0.146
GR	AllBanks (Weighted)	0.383	0.247	0.519	0.417	0.880	0.975
GR	AllBanks (Unweighted)	0.102	0.157	0.502	0.083*	0.302	0.262
AllBanks (Weighted)	AllCountries (Weighted)	0.824	0.672	0.668	0.277	0.356	0.293
AllBanks (Unweighted)	AllCountries (Unweighted)	0.872	0.626	0.415	0.308	0.572	0.525
AllBanks (Weighted)	GR	0.100	0.305	0.573	0.478	0.269	0.489
AllBanks (Unweighted)	GR	0.198	0.103	0.061*	0.087*	0.278	0.485

Period 2							
Dependent Variable	Independent Variable	l=1	l=2	l=3	l=4	l=5	l=6
Panel A							
GR	GR_Banks	0.736	0.837	0.861	0.852	0.790	0.870
PT	PT_Banks	0.939	0.962	0.975	0.720	0.775	0.840
IT	IT_Banks	0.588	0.131	0.187	0.329	0.575	0.893
SP	SP_Banks	0.672	0.444	0.492	0.557	0.779	0.751
IR	IR_Banks	0.788	0.695	0.375	0.505	0.600	0.791
FR	FR_Banks	0.720	0.443	0.421	0.652	0.859	0.823
NL	NL_Banks	0.215	0.452	0.483	0.822	0.706	0.787
DE	DE_Banks	0.377	0.079***	0.065*	0.223	0.784	0.761
GR_Banks	GR	0.424	0.224	0.481	0.561	0.291	0.500
PT_Banks	PT	0.232	0.466	0.526	0.625	0.646	0.604
IT_Banks	IT	0.287	0.280	0.660	0.937	0.701	0.736
SP_Banks	SP	0.232	0.220	0.789	0.917	0.841	0.821
IR_Banks	IR	0.415	0.552	0.565	0.296	0.178	0.332
FR_Banks	FR	0.546	0.344	0.167	0.056*	0.307	0.283
NL_Banks	NL	0.282	0.439	0.147	0.636	0.677	0.365
DE_Banks	DE	0.007*	0.215	0.449	0.599	0.099*	0.030**
Panel B							
GR	PT_Banks	0.019**	0.039**	0.137	0.076*	0.144	0.370
GR	IT_Banks	0.052***	0.081***	0.078*	0.031**	0.030**	0.072*
GR	SP_Banks	0.081***	0.064***	0.010**	0.049**	0.062*	0.162
GR	FR_Banks	0.047**	0.093***	0.190	0.284	0.119	0.151
GR	IR_Banks	0.709	0.732	0.380	0.477	0.585	0.818
GR	NL_Banks	0.584	0.332	0.248	0.574	0.406	0.471
GR	DE_Banks	0.389	0.018**	0.119	0.276	0.640	0.833
PT_Banks	GR	0.073***	0.197	0.293	0.321	0.154	0.128
IT_Banks	GR	0.284	0.435	0.204	0.359	0.702	0.633
SP_Banks	GR	0.394	0.256	0.092*	0.072*	0.070*	0.350
FR_Banks	GR	0.111	0.378	0.117	0.218	0.394	0.367
IR_Banks	GR	0.254	0.544	0.556	0.342	0.313	0.504
NL_Banks	GR	0.137	0.189	0.110	0.133	0.143	0.180
DE_Banks	GR	0.184	0.280	0.273	0.762	0.863	0.881
Panel C							
AllCountries (Weighted)	AllBanks (Weighted)	0.156	0.307	0.176	0.319	0.356	0.450
AllCountries (Unweighted)	AllBanks (Unweighted)	0.764	0.149	0.218	0.570	0.622	0.768
GR	AllBanks (Weighted)	0.090***	0.132	0.183	0.398	0.347	0.503
GR	AllBanks (Unweighted)	0.222	0.439	0.528	0.497	0.671	0.523
AllBanks (Weighted)	AllCountries (Weighted)	0.337	0.498	0.164	0.404	0.297	0.655
AllBanks (Unweighted)	AllCountries (Unweighted)	0.709	0.934	0.049**	0.047**	0.087*	0.030**
AllBanks (Weighted)	GR	0.101	0.370	0.083*	0.108	0.130	0.270
AllBanks (Unweighted)	GR	0.376	0.633	0.216	0.334	0.502	0.771

Note: The table reports p-values of the nonlinear D&P Granger causality test on the GARCH-BEKK-filtered data for lags l_X=l_Y=1,2,3,4,5,6. We test the null hypothesis that there is no Granger causality between the sovereign and bank CDS spreads. *,**,*** denote rejection of the null hypothesis at the 10%, 5%, and 1% significance level, respectively.

1.6. Conclusions

In this study, we provide evidence on the changing dynamics characterizing the nexus between sovereign and bank credit risk around an important event during the European sovereign debt crisis, specifically the period before and after the announcement of the PSI. Our results show that there were significant bidirectional causal interrelationships between sovereign and bank credit risk in the period before the PSI, especially from sovereign credit spreads to the corresponding banking sector credit spreads. We find that the dynamic interlinkages between banks and sovereigns in terms of magnitude and persistence weakened after the PSI, and this result holds consistently across a step-by-step procedure involving linear and nonlinear causality tests both in terms of raw and filtered data. We surmise this evidence supports the view that the PSI was successful in weakening the nexus between banks and sovereigns, and in this sense it may be viewed as a positive outcome.

In the case of Greece, we find bidirectional causality between banks and their sovereign in the first period but surprisingly little evidence of causality in the second period aside from some weak evidence of nonlinear causality at longer lags. We surmise this evidence is consistent with an important element in the PSI providing Greek banks full recovery through recapitalization for portfolio losses suffered as a result of the PSI haircut, thereby preventing country-specific risk turning to a systemic risk. Additionally, our results suggest that strong causal effects running from Greek sovereign CDS to bank CDS of other Eurozone countries in the period before the PSI appears to have been greatly subdued in the following subperiod.

The extension of causality testing to a nonlinear framework captures more efficiently the unpredictable and abnormal variations in CDS markets that occurred under the crisis conditions. More specifically, the D&P (2006) Granger causality test provides significant evidence of nonlinear causal relationship between sovereign and bank CDS series. We observe that the D&P causality test results indicated additional Granger causal relationships that were not evident from linear causality tests, specifically for Portuguese banks on their sovereign in the first period, Italian banks on their sovereign and Greek sovereign on Greek banks in the second period. Additionally, whilst most linear causal relationships vanished after VAR/VEC filtering, nonlinear causal linkages were still present and more importantly persisted after multivariate GARCH filtering during both periods.

European banks had significant albeit varying exposures to Greek sovereign debt, with the effectiveness of the PSI program resting in its ability to balance these risks while delivering a positive outcome in terms of placing Greek sovereign debt on a more sustainable path. Hence, the success of the program rested on its ability to raise investor confidence improving Greece's prospects to regain access in international financial markets, while mitigating the transmission of the Greek sovereign crisis to the rest of the Eurozone.

Moreover, an indication of the effectiveness of the PSI was the significant reduction of deposit outflows from the Greek banking system in the period after the program. According to the Bank of Greece deposits from July 2012 to November 2014 increased by EUR 13.7 billion. Combined with the process of recapitalization, this led to a more stable banking sector, which was necessary to ensure the sustainability of the Greek banks and reduce systemic risk. The latter resulted in the upgrade of the creditworthiness of Greece according to the Standard and Poor's. As noted by The Economist "the impact of laying out a credible path to debt sustainability could be powerful. Greeks could start to believe they have a way out of the crisis; investors could put money in the country with more certainty. It could create a positive circle of confidence and growth." (The Economist 10 Nov. 2012). With hindsight, the debt restructuring was necessary, albeit not sufficient, to deal with an increasingly dire situation (see Zettelmeyer et al. 2013).

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Appendix

Table A1: The sample of countries and banking institutions

	Banking Institutions
GR_Banks	National Bank of Greece
	EFG Eurobank Ergasias SA
	Alpha Bank AE
PT_Banks	Banco Espirito Santo SA
	Banco Commercial Portugues SA
IT_Banks	Mediobanca SpA
	Banca Popolare di Milano
	Banca Monte dei Paschi Siena
SP_Banks	Banco de Sabadell SA
	Banco Bilbao Vizcaya Argentaria SA
	Banco Popular Espanol SA
IR_Banks	Bank of Ireland
FR_Banks	Natixis
	BNP Paribas SA
	Credit Agricole SA
NL_Banks	Cooperatieve Centrale Raiffeisen Boerenleenbank B.A (Rabobank)
	F. Van Lanschot Bankiers NV
DE_Banks	Commerzbank AG
	Deutsche Bank AG
	IKB Deutsche Industriebank AG
	Bayerische Landesbank

Note: The table presents the countries and the banking institutions of our sample. We weigh the bank CDS, in order to form the index of bank CDS spreads for each country, based on their total liabilities in each year.

Table A2: Pairwise correlations between the log-differences of sovereign and bank CDS spreads

	1st period	2nd period
GR-GR_Banks	0.3283	0.0543
PT-PT_Banks	0.6361	0.3502
IT-IT_Banks	0.6607	0.6261
SP-SP_Banks	0.6691	0.5783
IR-IR_Banks	0.3103	0.1392
FR-FR_Banks	0.6190	0.5085
NL-NL_Banks	0.4254	0.3582
DE-DE_Banks	0.4991	0.3418
GR-PT_Banks	0.5088	0.0129
GR-IT_Banks	0.5234	0.1768
GR-SP_Banks	0.5293	0.1433
GR-IR_Banks	0.2595	-0.0045
GR-FR_Banks	0.5232	0.1960
GR-NL_Banks	0.4390	0.1722
GR-DE_Banks	0.4988	0.1835
AllCountries - AllBanks (Weighted)	0.7376	0.4485
GR-AllBanks (Weighted)	0.5642	0.1794
AllCountries - AllBanks (Unweighted)	0.5574	0.0531
GR-AllBanks (Unweighted)	0.4516	0.0829

Note: Period 1 ranges from 01/01/2009 to 26/10/2011 and period 2 from 27/10/2011 to 30/05/2014.

Table A3: Unit root test results

Panel A: Unit root test results for sovereign CDS spreads in the 1st period						
Sovereign CDS spreads	Log-series in levels			Log-series in first differences		
	PP	ADF	KPSS	PP	ADF	KPSS
GR	0.774	0.506	2.940***	-20.728***	-20.728***	0.323***
PT	-0.168	-0.189	2.913***	-21.405***	-16.073***	0.144*
IT	-1.001	-1.496	1.308***	-20.762***	-21.344***	0.244***
SP	-1.109	-1.069	2.355***	-22.401***	-16.327***	0.078
IR	-0.750	-0.814	2.413***	-22.368***	-22.495***	0.113
FR	-0.890	-1.157	1.473***	-21.035***	-21.413***	0.179**
NL	-1.465	-1.749	0.370*	-20.870***	-21.173***	0.329***
DE	-2.104	-2.289	0.321	-24.073***	-24.221***	0.109
AllCountries (Weighted)	-2.079	-0.254	1.340***	-19.359***	-16.376***	0.039
AllCountries (Unweighted)	0.383	0.344	1.590***	-19.407***	-19.899***	0.037
Panel B: Unit root test results for bank CDS spreads in the 1st period						
Bank CDS spreads	Log-series in levels			Log-series in first differences		
	PP	ADF	KPSS	PP	ADF	KPSS
GR_Banks	0.474	1.052	2.540***	-24.210***	-22.271***	0.381***
PT_Banks	-0.425	-0.410	3.019***	-20.908***	-20.699***	0.073
IT_Banks	-0.181	-0.289	2.393***	-23.306***	-23.289***	0.247***
SP_Banks	-0.663	-0.862	2.383***	-20.229***	-20.666***	0.111
IR_Banks	-0.698	-0.532	2.257***	-26.643***	-26.349***	0.147**
FR_Banks	-1.029	-1.591	1.535***	-20.891***	-21.456***	0.125*
NL_Banks	-1.986	-1.949	0.783***	-22.128***	-22.091***	0.275***
DE_Banks	-1.436	-1.757	0.845***	-22.190***	-25.545***	0.183**
AllBanks (Weighted)	-0.345	-0.529	1.890***	-20.638***	-20.886***	0.045
AllBanks (Unweighted)	-0.097	-0.045	2.330***	-22.825***	-22.536***	0.093

Panel C: Unit root test results for sovereign CDS spreads in the 2nd period						
Sovereign CDS spreads	Log-series in levels			Log-series in first differences		
	PP	ADF	KPSS	PP	ADF	KPSS
GR	-0.264	-0.081	2.877***	-25.014***	24.784***	0.196**
PT	-0.347	-0.358	2.708***	-20.652***	-20.756***	0.077
IT	-0.481	0.729	2.720***	-21.661***	-21.971***	0.070
SP	0.989	0.112	2.709***	-22.667***	-22.789***	0.267***
IR	-0.583	-0.605	2.975***	-27.338***	-11.694***	0.063
FR	-1.354	-1.423	2.884***	-25.511***	-25.364***	0.046
NL	-0.515	-0.495	2.646***	-22.669***	-22.619***	0.082
DE	-1.623	-1.623	2.717***	-25.064***	-25.080***	0.081
AllCountries (Weighted)	0.002	-0.007	1.040***	-23.160***	-23.139***	0.080
AllCountries (Unweighted)	-1.535	-1.549	0.702**	-25.599***	-25.598***	0.031

Panel D: Unit root test results for bank CDS spreads in the 2nd period						
Bank CDS spreads	Log-series in levels			Log-series in first differences		
	PP	ADF	KPSS	PP	ADF	KPSS
GR_Banks	0.453	0.638	3.095***	-30.924***	-31.374***	0.126*
PT_Banks	-0.245	-0.081	2.635***	-24.699***	-24.464***	0.106
IT_Banks	0.435	0.359	1.591***	-19.979***	-19.945***	0.428*
SP_Banks	0.471	0.539	2.551***	-21.587***	-21.362***	0.298*
IR_Banks	-0.635	-0.625	3.000***	-25.756***	-25.721***	0.066
FR_Banks	-0.329	0.501	2.787***	-20.549***	-20.850***	0.101
NL_Banks	-0.331	-0.398	2.219***	-23.356***	-23.399***	0.150**
DE_Banks	-0.661	-1.001	2.714***	-20.795***	-21.225***	0.056
AllBanks (Weighted)	0.405	0.285	0.834***	-20.711***	-20.768***	0.043
AllBanks (Unweighted)	0.533	0.616	0.673**	-23.608***	-23.322***	0.086

Note: The table presents the results after applying the breakpoint (p-values), the PP (p-values) and the KPSS (LM- statistics) unit root tests. Period 1 ranges from 01/01/2009 to 26/10/2011 and period 2 from 27/10/2011 to 05/30/2014. *, **, *** denote statistical significance at the 10%, 5%, and 1% level, respectively.

Table A4: Bivariate cointegration test results

Panel A: Johansen test for sovereign and bank CDS spreads-1st period					
Variables	Lags	Trace test		Maximum Eigenvalue test	
		r=0	r=1	r=0	r=1
GR-GR_Banks	9	**20.5857**	4.5088	**16.0768**	4.5088
		(0.0451)	(0.3416)	**(0.0468)**	(0.3416)
PT-PT_Banks	6	**23.0358**	1.0975	**21.9382**	1.0975
		(0.0202)	(0.9384)	**(0.0049)**	(0.9384)
IT-IT_Banks	6	14.0930	0.8718	13.2211	0.8718
		(0.2831)	(0.9666)	(0.1257)	(0.9666)
SP-SP_Banks	4	**33.0615**	2.7970	**30.2645**	2.7970
		(0.0005)	(0.6193)	**(0.0002)**	(0.6193)
IR-IR_Banks	4	**20.8063**	0.0880	**20.7182**	0.0880
		(0.0421)	(1.0000)	**(0.0080)**	(1.0000)
FR-FR_Banks	3	11.7455	0.9937	10.7517	0.9937
		(0.4719)	(0.9523)	(0.2707)	(0.9523)
NL-NL_Banks	3	10.6876	2.0125	8.6751	2.0125
		(0.5724)	(0.7752)	(0.4694)	(0.7752)
DE-DE_Banks	7	12.1186	3.0664	9.0521	3.0664
		(0.4383)	(0.4383)	(0.4283)	(0.4383)
GR-PT_Banks	4	**21.3381**	5.8710	15.4670	5.8710
		(0.0354)	(0.2009)	(0.0582)	(0.2009)
GR-IT_Banks	7	13.2075	4.0437	9.1637	4.0437
		(0.3475)	(0.4057)	(0.0582)	(0.4057)
GR-SP_Banks	2	13.8794	2.5754	11.3039	2.5754
		(0.2978)	(0.6626)	(0.2301)	(0.6626)
GR-IR_Banks	1	9.2849	1.1337	8.1512	1.1337
		(0.7094)	(0.9333)	(0.5298)	(0.9333)
GR-FR_Banks	9	10.7376	2.9043	7.8332	2.9043
		(0.5675)	(0.5987)	(0.5677)	(0.5987)
GR-NL_Banks	5	14.7500	2.6533	12.0967	2.6533
		(0.2410)	(0.6473)	(0.1804)	(0.6473)
GR-DE_Banks	9	10.3852	2.6888	7.6964	2.6888
		(0.6020)	(0.6403)	(0.5843)	(0.6403)
AllCountries-AllBanks	4	**21.084**	0.9657	**20.1189**	0.9657
(Weighted)		**(0.0385)**	(0.9558)	**(0.0102)**	(0.9558)
AllCountries-AllBanks	3	20.2618	1.1492	15.9558	1.1492
(Unweighted)		(0.1286)	(0.9310)	(0.0589)	(0.9310)
GR-AllBanks	2	19.4878	4.4335	15.0512	4.4335
(Weighted)		(0.0637)	(0.3514)	(0.0674)	(0.3514)
GR-AllBanks	2	**20.4981**	3.6123	**16.8857**	3.6123
(Unweighted)		**(0.0464)**	(0.4729)	**(0.0348)**	(0.4729)

Panel B : Johansen test for sovereign and bank CDS spreads-2nd period					
Variables	Lags	Trace test		Maximum Eigenvalue test	
		r=0	r=1	r=0	r=1
GR-GR_Banks	3	**26.8948** **(0.0052)**	5.9701 (9.1645)	**20.9247** **(0.0074)**	5.9701 (9.1645)
PT-PT_Banks	1	13.6687 (0.3128)	4.7122 (0.3164)	8.9565 (0.4385)	4.7122 (0.3164)
IT-IT_Banks	2	15.3364 (0.2077)	3.7370 (0.4527)	1.5993 (0.2105)	3.7370 (0.4527)
SP-SP_Banks	2	**25.6525** **(0.0082)**	3.6568 (0.4656)	**21.9957** **(0.0048)**	3.6568 (0.4656)
IR-IR_Banks	7	**26.9218** **(0.0052)**	20.2618 (0.5596)	**23.8076** **(0.0023)**	20.2618 (0.5596)
FR-FR_Banks	3	15.0233 (0.2250)	5.8488 (0.2087)	9.1744 (0.4153)	5.8488 (0.2087)
NL-NL_Banks	1	7.6735 (0.8501)	1.8177 (0.8136)	5.8557 (0.8039)	1.8177 (0.8136)
DE-DE_Banks	1	18.8401 (0.0775)	7.1230 (0.1201)	11.7171 (0.2030)	7.1230 (0.1201)
GR-PT_Banks	1	15.8183 (0.1831)	4.5360 (0.3381)	11.2822 (0.2316)	4.5360 (0.3381)
GR-IT_Banks	5	16.7381 (0.1426)	2.4613 (0.6852)	14.2767 (0.0881)	2.4613 (0.6852)
GR-SP_Banks	7	19.9044 (0.0559)	6.4064 (0.1616)	13.4980 (0.1147)	6.4064 (0.1616)
GR-IR_Banks	1	**31.0770** **(0.0011)**	8.6790 (0.0618)	**22.3980** **(0.0041)**	8.6790 (0.0618)
GR-FR_Banks	3	14.3111 (0.2686)	3.8796 (0.4303)	10.4315 (0.2967)	3.8796 (0.4303)
GR-NL_Banks	7	19.6660 (0.0602)	5.1500 (0.1794)	13.5159 (0.1140)	5.1500 (0.1794)
GR-DE_Banks	6	24.2342 (0.0134)	9.5132 (0.0429)	14.7210 (0.0756)	9.5132 (0.0429)
AllCountries-AllBanks (Weighted)	1	13.2056 (0.3476)	4.1108 (0.3959)	9.0947 (0.4237)	4.1108 (0.3959)
AllCountries-AllBanks (Unweighted)	2	32.6581 (0.0006)	9.1645 (0.0239)	21.8238 (0.0052)	9.1645 (0.0239)
GR-AllBanks (Weighted)	6	18.2484 (0.0924)	4.9238 (0.2919)	13.3245 (0.1215)	4.9238 (0.2919)
GR-AllBanks (Unweighted)	6	**25.5706** **(0.0084)**	5.2821 (0.2539)	**20.2885** **(0.0095)**	5.2821 (0.2539)

Note: The table presents the results from the Johansen's trace and maximum eigenvalue tests. The bold values indicate the sovereign and bank CDS series where a long-term relation is observed. Period 1 ranges from 01/01/2009 to 26/10/2011 and period 2 from 27/10/2011 to 30/05/2014. **r=0** denotes the null hypothesis. The control is performed at the 5% significance level.

Table A5: Hsiao causality results

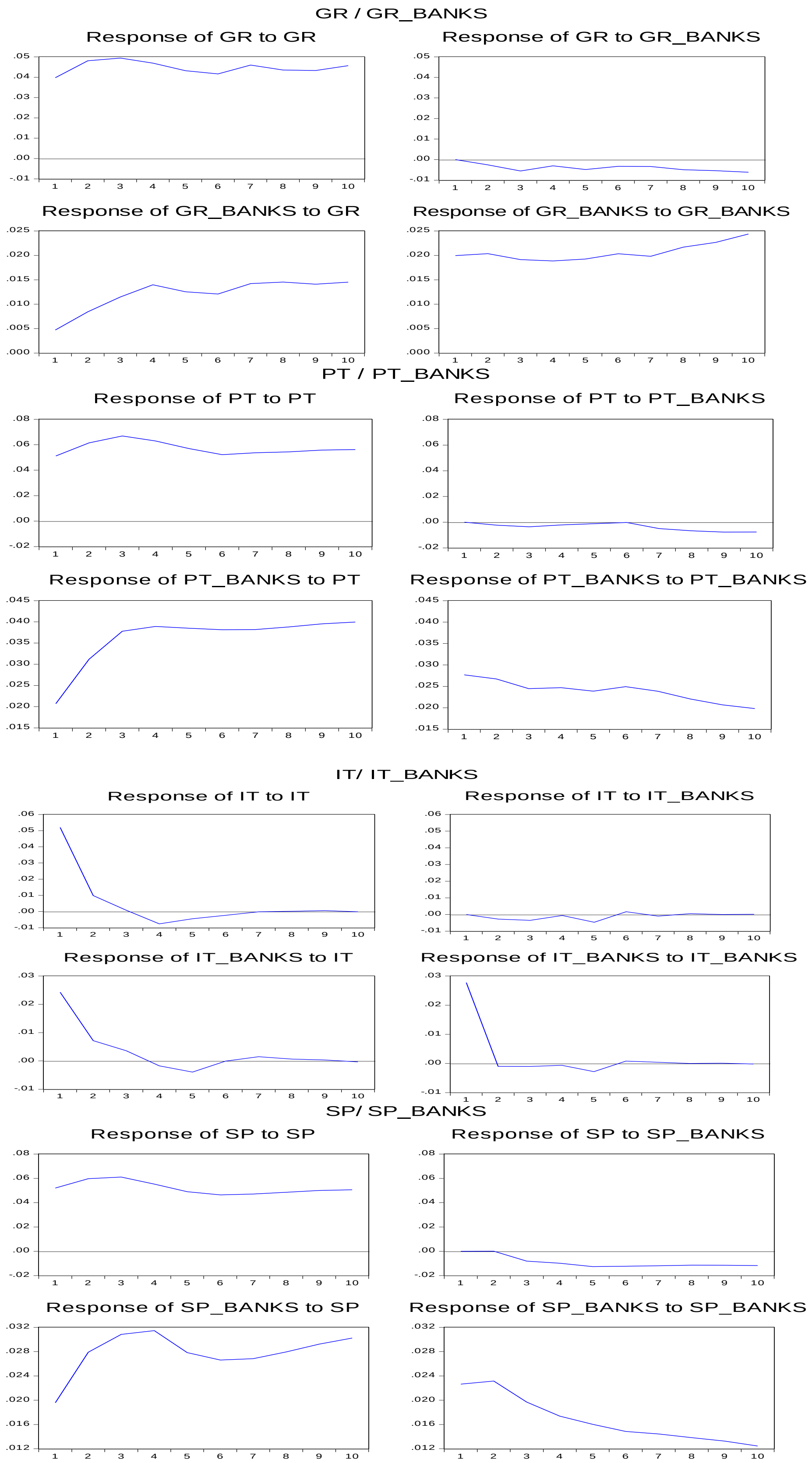
Period 1				
Controlled variable	Manipulated variable	FPE (k,0)	FPE (k,l)	Causality
Panel A				
GR	GR_Banks	0.00219 (25,0)	0.00217 (25,6)	YES
PT	PT_Banks	0.00303 (18,0)	0.00304 (18,9)	NO
IT	IT_Banks	0.00317 (4,0)	0.00315 (4,2)	YES
SP	SP_Banks	0.00303 (18,0)	0.00301 (18,2)	YES
IR	IR_Banks	0.00193 (21,0)	0.00193 (21,1)	NO
FR	FR_Banks	0.00220 (6,0)	0.00218 (6,3)	YES
NL	NL_Banks	0.00153 (18,0)	0.00149 (18,3)	YES
DE	DE_Banks	0.00315 (7,0)	0.00313 (7,1)	YES
GR_Banks	GR	0.00054 (24,0)	0.00050 (24,8)	YES
PT_Banks	PT	0.00138 (20,0)	0.00130 (20,3)	YES
IT_Banks	IT	0.00154 (18,0)	0.00148 (18,1)	YES
SP_Banks	SP	0.00105 (13,0)	0.00101 (13,4)	YES
IR_Banks	IR	0.00187 (9,0)	0.00184 (9,12)	YES
FR_Banks	FR	0.00144 (4,0)	0.00142 (4,18)	YES
NL_Banks	NL	0.00082 (14,0)	0.00080 (14,2)	YES
DE_Banks	DE	0. 00121 (5,0)	0.00117 (5,24)	YES
Panel B				
GR	PT_Banks	0.00219 (25,0)	0.00216 (25,4)	YES
GR	IT_Banks	0.00220 (25,0)	0.00217 (25,2)	YES
GR	SP_Banks	0.00220 (25,0)	0.00217 (25,4)	YES
GR	IR_Banks	0.00220 (25,0)	0.00219 (25,1)	YES
GR	FR_Banks	0.00220 (25,0)	0.00219 (25,3)	YES
GR	NL_Banks	0.00220 (25,0)	0.00217 (25,1)	YES
GR	DE_Banks	0.00220 (25,0)	0.00217 (25,8)	YES
PT_Banks	GR	0.00139 (20,0)	0.00132 (20,5)	YES
IT_Banks	GR	0.00154 (18,0)	0.00147 (18,17)	YES
SP_Banks	GR	0.00108 (13,0)	0.00105 (13,12)	YES
IR_Banks	GR	0.00195 (9,0)	0.00194 (9,1)	YES
FR_Banks	GR	0.00144 (4,0)	0.00141 (4,18)	YES
NL_Banks	GR	0.00082 (14,0)	0.00080 (14,5)	YES
DE_Banks	GR	0.00121 (5,0)	0.00119 (5,12)	YES
Panel C				
AllCountries (Weighted)	AllBanks (Weighted)	0.00178 (18,0)	0.00178 (18,2)	YES
AllCountries (Unweighted)	AllBanks (Unweighted)	0.00171 (18,0)	0.00171 (18,2)	YES

GR	AllBanks (Weighted)	0.00220 (25,0)	0.00217 (25,2)	YES
GR	AllBanks (Unweighted)	0.00219 (25,0)	0.00216 (25,2)	YES
AllBanks (Weighted)	AllCountries (Weighted)	0.00078 (5,0)	0.00077 (5,1)	YES
AllBanks (Unweighted)	AllCountries (Unweighted)	0.00085 (9,0)	0.00081 (9,1)	YES
AllBanks (Weighted)	GR	0.00080 (5,0)	0.00078 (5,18)	YES
AllBanks (Unweighted)	GR	0.00084 (9,0)	0.00081 (9,1)	YES
		Period 2		
Controlled variable	Manipulated variable	FPE (k,0)	FPE (k,l)	Causality
Panel A				
GR	GR_Banks	0.00391 (12,0)	0.00392 (12,1)	NO
PT	PT_Banks	0.00905 (2,0)	0.00090 (2,7)	NO
IT	IT_Banks	0.00122 (2,0)	0.00122 (2,1)	NO
SP	SP_Banks	0.00128 (5,0)	0.00128 (5,1)	NO
IR	IR_Banks	0.00086 (17,0)	0.00084 (17,5)	YES
FR	FR_Banks	0.00203 (18,0)	0.00195 (18,1)	YES
NL	NL_Banks	0.00069 (1,0)	0.00069 (1,1)	NO
DE	DE_Banks	0.00228 (2,0)	0.00228 (2,4)	YES
GR_Banks	GR	0.00034 (2,0)	0.00034 (2,1)	NO
PT_Banks	PT	0.00057 (3,0)	0.00056 (3,1)	YES
IT_Banks	IT	0.00062 (1,0)	0.00061 (1,1)	YES
SP_Banks	SP	0.00056 (1,0)	0.00056 (1,1)	YES
IR_Banks	IR	0.00036 (3,0)	0.00036 (3,3)	YES
FR_Banks	FR	0.00086 (1,0)	0.00085 (1,10)	YES
NL_Banks	NL	0.00062 (1,0)	0.00061 (1,1)	YES
DE_Banks	DE	0.00077 (1,0)	0.00077 (1,1)	NO
Panel B				
GR	PT_Banks	0.00397 (10,0)	0.00398 (10,1)	NO
GR	IT_Banks	0.00397 (10,0)	0.00392 (10,5)	YES
GR	SP_Banks	0.00397 (10,0)	0.00397 (10,3)	YES
GR	IR_Banks	0.00394 (12,0)	0.00394 (12,15)	YES
GR	FR_Banks	0.00397 (10,0)	0.00389 (10,25)	YES
GR	NL_Banks	0.00397 (10,0)	0.00397 (10,5)	YES
GR	DE_Banks	0.00397 (10,0)	0.00393 (10,25)	YES
PT_Banks	GR	0.00057 (3,0)	0.00056 (3,1)	YES
IT_Banks	GR	0.00062 (1,0)	0.00062 (1,11)	YES

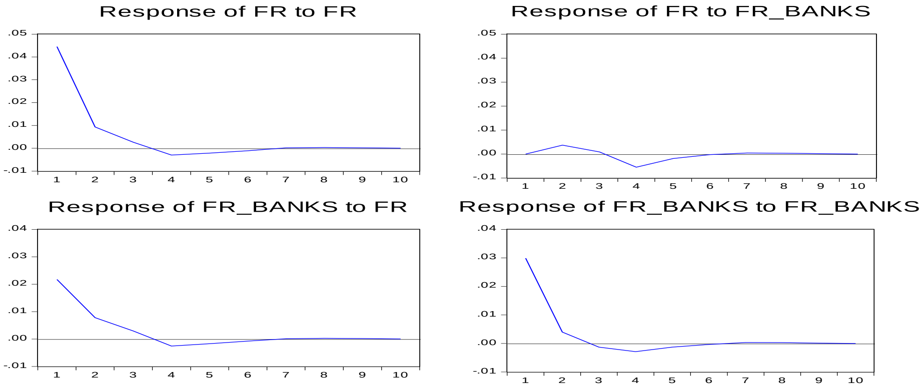
SP_Banks	GR	0.00057 (1,0)	0.00057 (1,11)	YES
IR_Banks	GR	0.00036 (3,0)	0.00036 (3,21)	YES
FR_Banks	GR	0.00086 (1,0)	0.00085 (1,11)	YES
NL_Banks	GR	0.00062 (1,0)	0.00062 (1,3)	YES
DE_Banks	GR	0.00077 (1,0)	0.00077 (1,5)	YES
Panel C				
AllCountries (Weighted)	AllBanks (Weighted)	0.00136 (18,0)	0.00134 (18,6)	YES
AllCountries (Unweighted)	AllBanks (Unweighted)	0.01842 (22,0)	0.01840 (22,1)	YES
GR	AllBanks (Weighted)	0.00397 (10,0)	0.00394 (10,1)	YES
GR	AllBanks (Unweighted)	0.00394 (12,0)	0.00395 (12,1)	NO
AllBanks (Weighted)	AllCountries (Weighted)	0.00033 (1,0)	0.00033 (1,1)	YES
AllBanks (Unweighted)	AllCountries (Unweighted)	0.00018 (1,0)	0.00018 (1,2)	NO
AllBanks (Weighted)	GR	0.00033 (1,0)	0,00033 (1,17)	YES
AllBanks (Unweighted)	GR	0.00018 (1,0)	0.00017 (12,1)	YES

Note: The numbers in the parentheses indicate the lags that give us the minimum FPEs for each pair of variables.

Figure A1: Impulse responses for sovereign and bank CDS spreads during the 1st period



FR/ FR_BANKS



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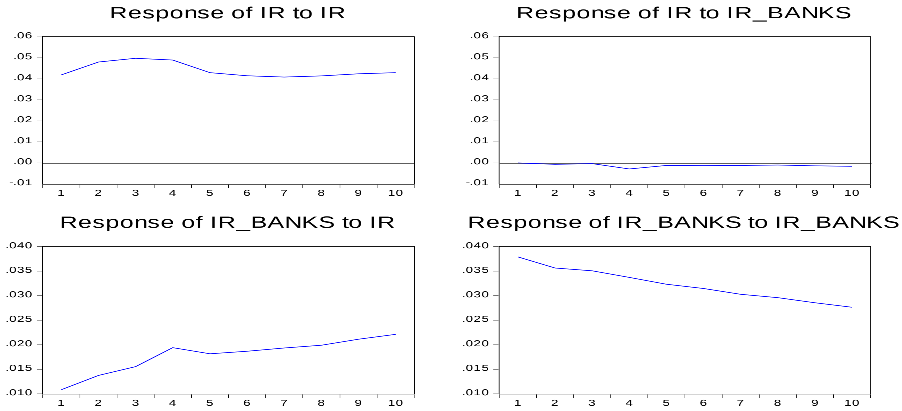

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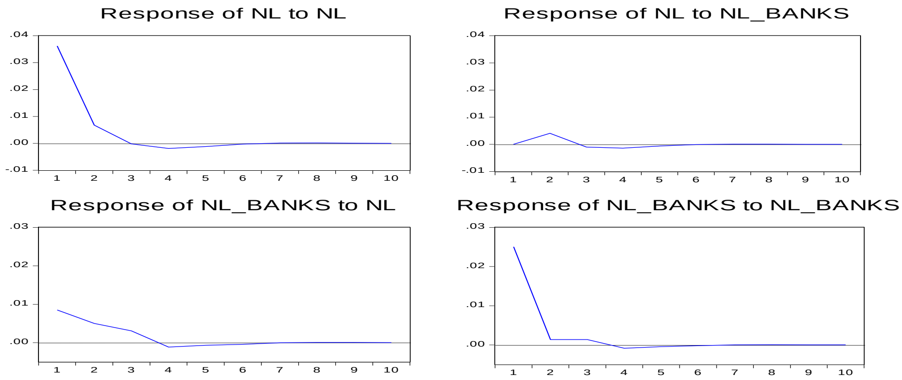

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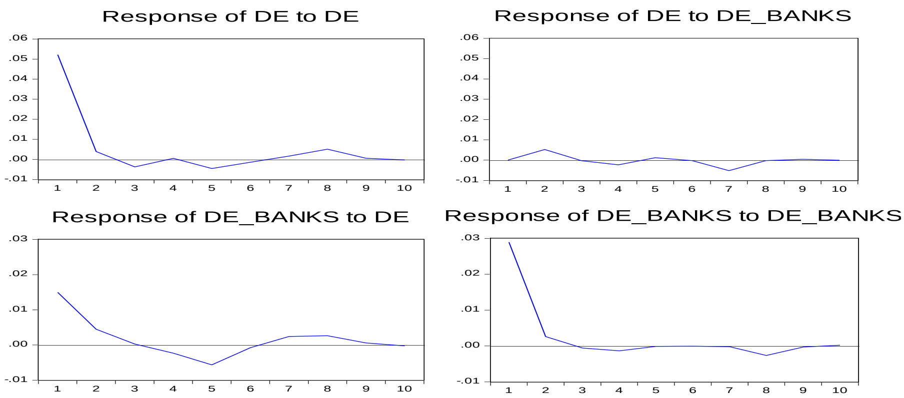

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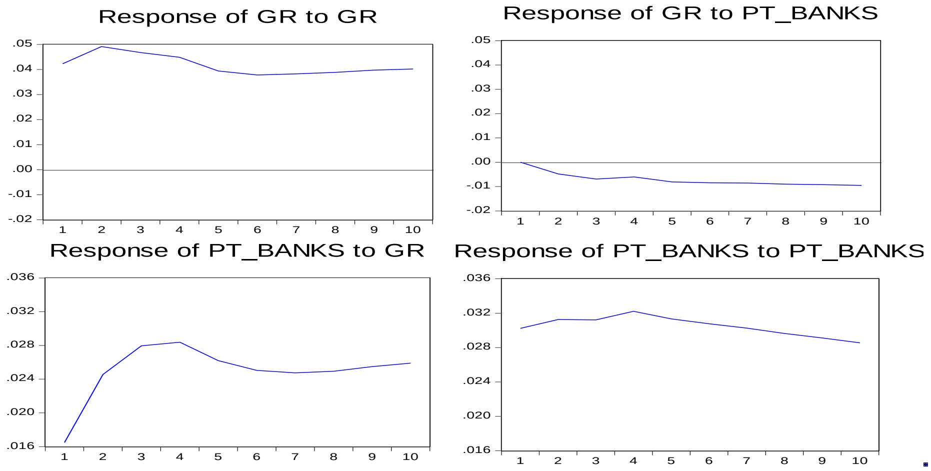
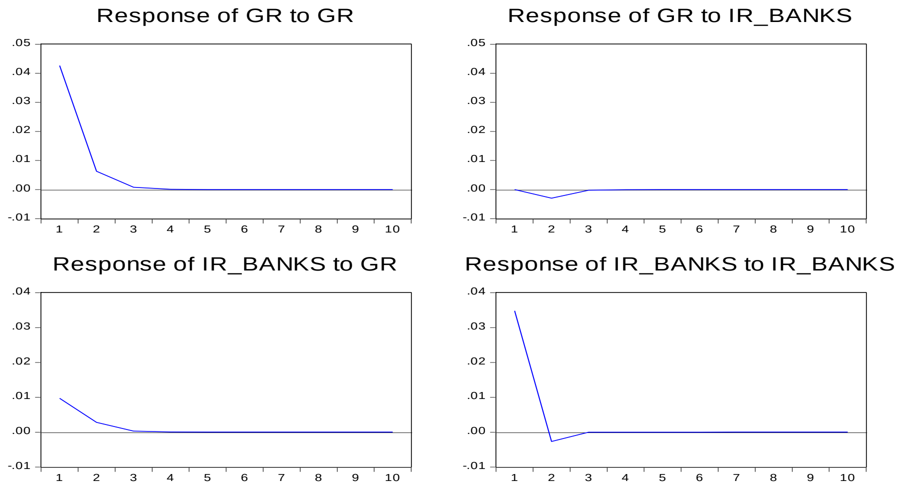


GR/ SP_BANKS

GR/ IR_BANKS



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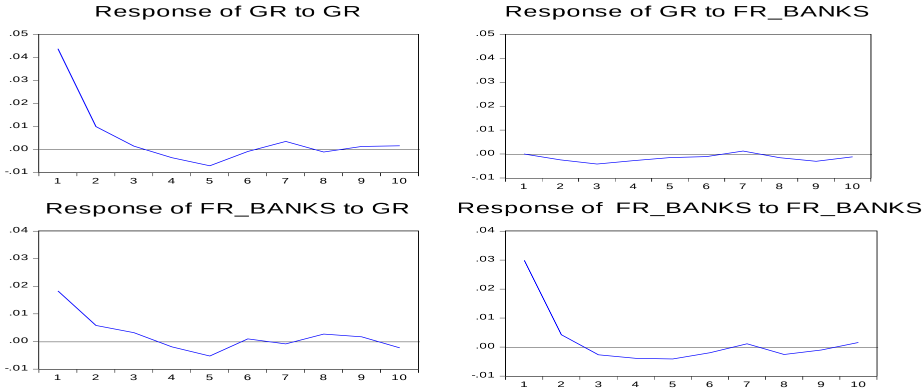
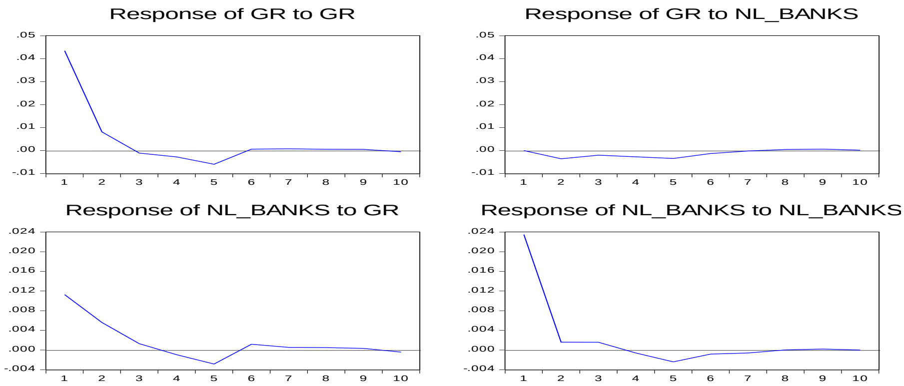


GR/ NL_BANKS



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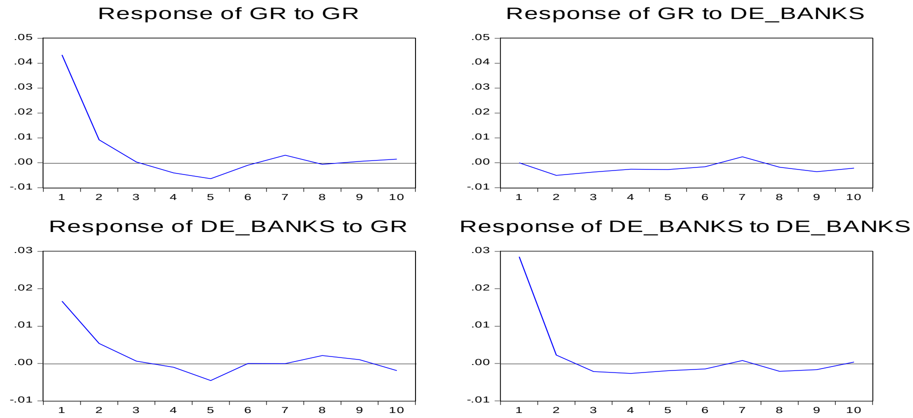
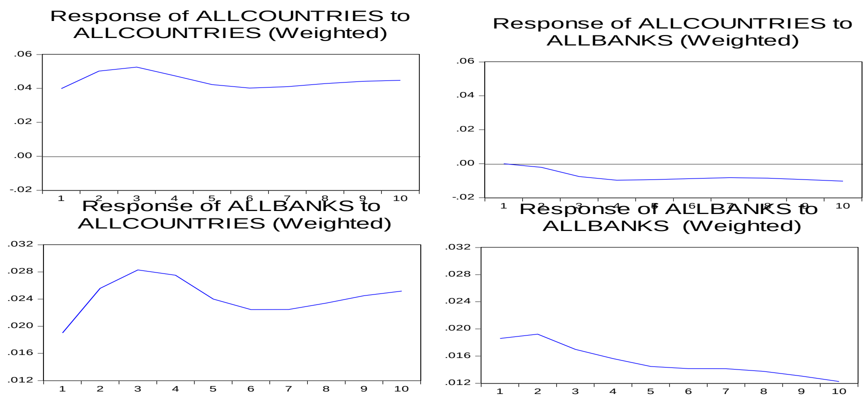
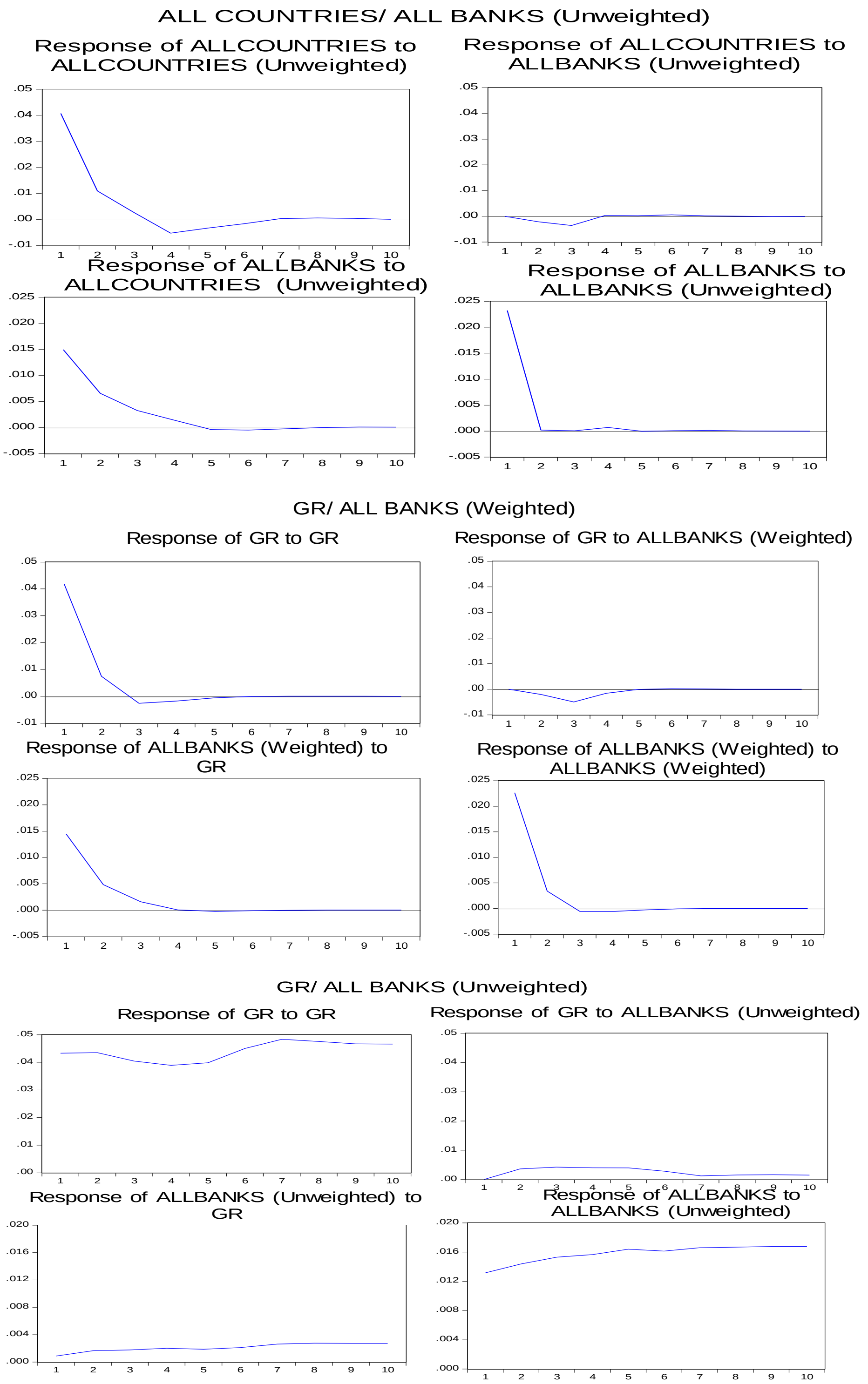


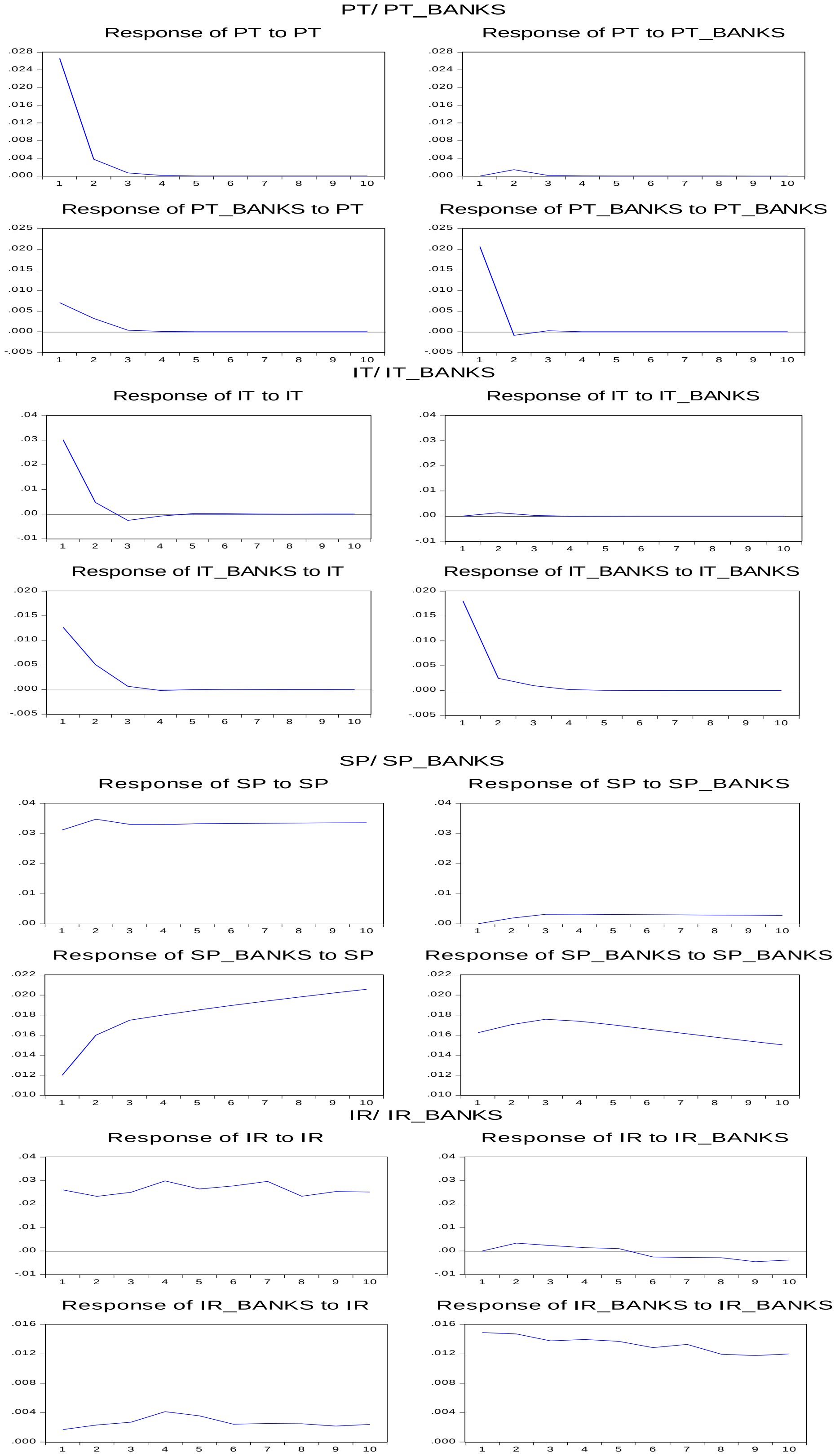
ALL COUNTRIES/ ALL BANKS (Weighted)





Note: The figures depict the impulse response functions for the sovereign and bank CDS spreads for the next 10 days after a shock to the estimated VAR or VEC model. Period 1 ranges from 01/01/2009 to 26/10/2011. X-axis denotes the number of days after the shock and Y-axis the response of a variable to a one standard deviation shock on the other variable.

Figure A2: Impulse responses for sovereign and bank CDS spreads during the 2nd period



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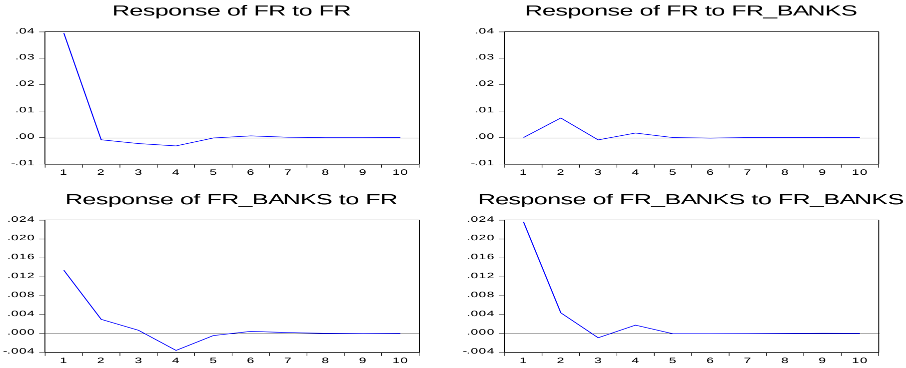

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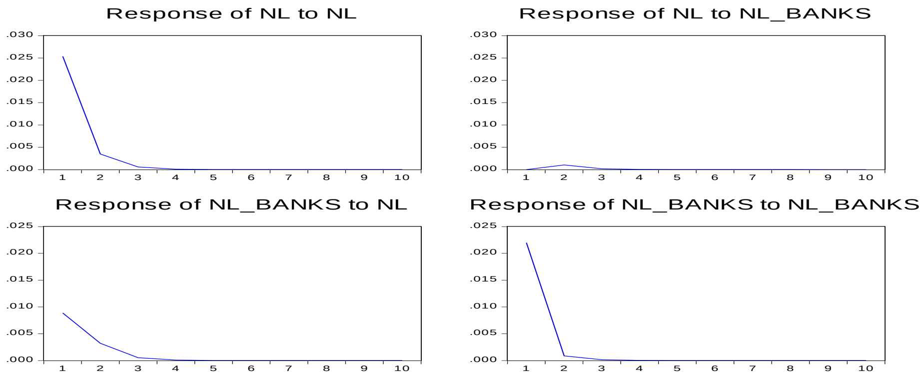

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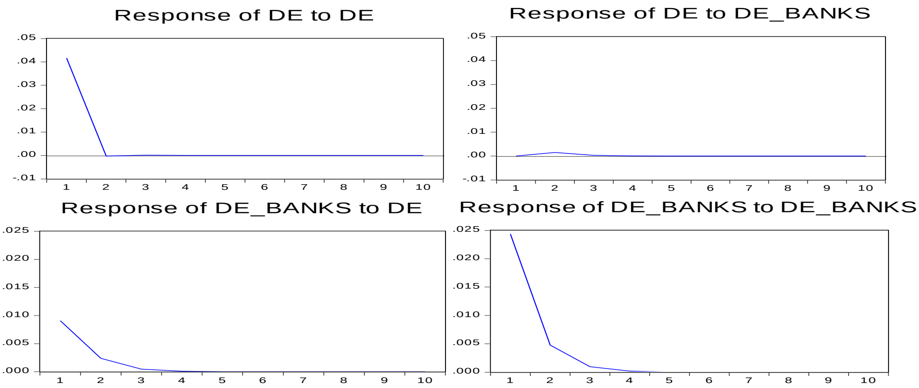

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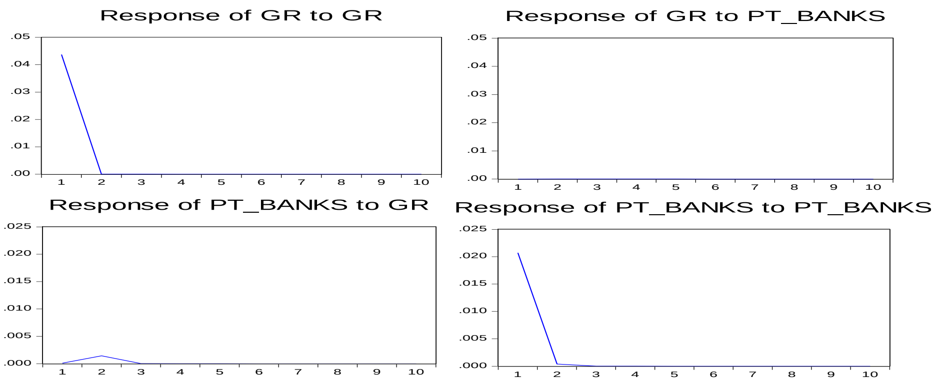

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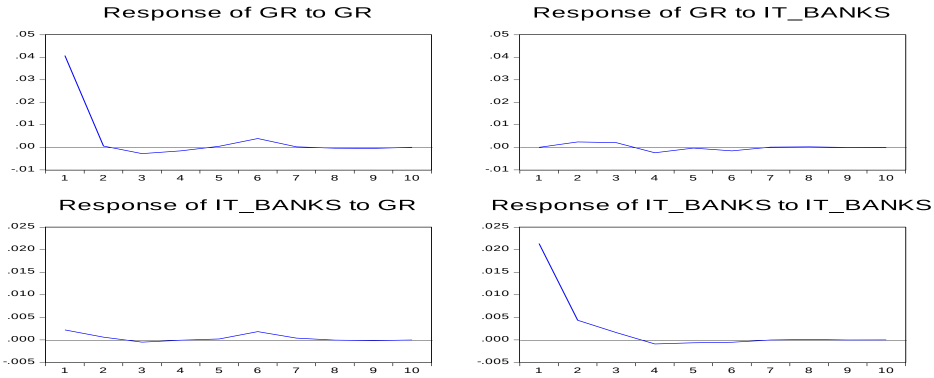

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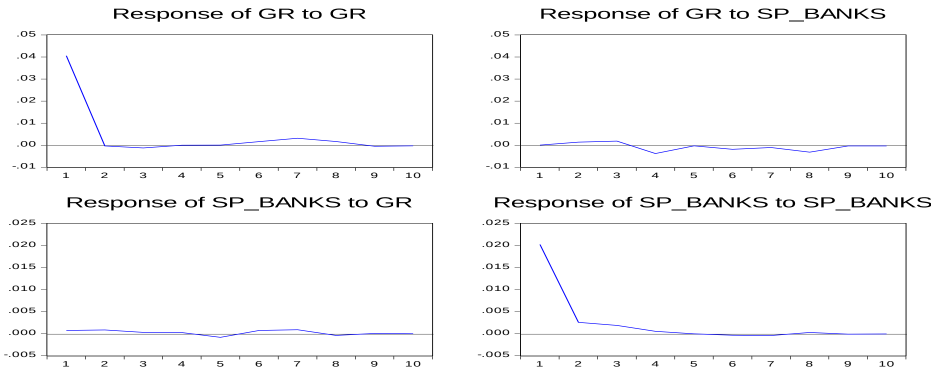

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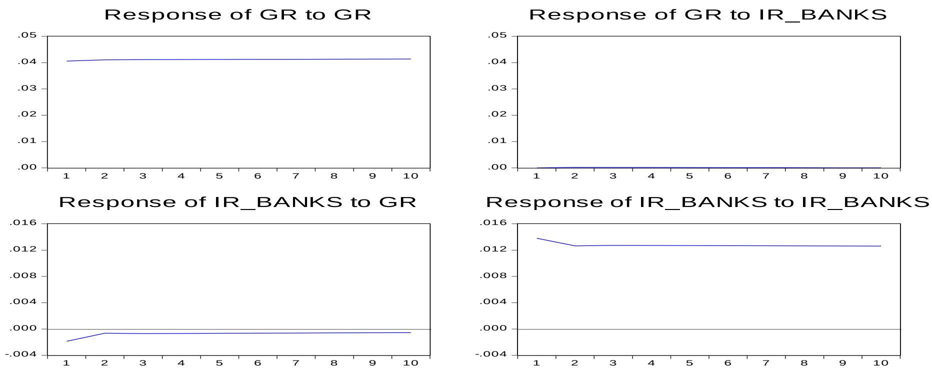

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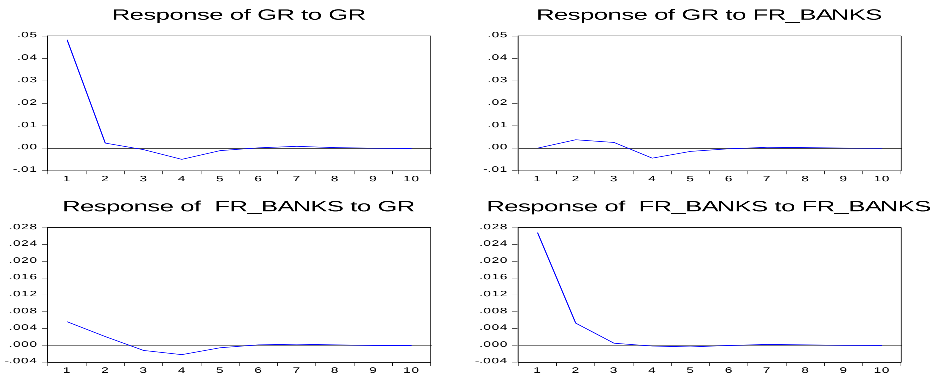
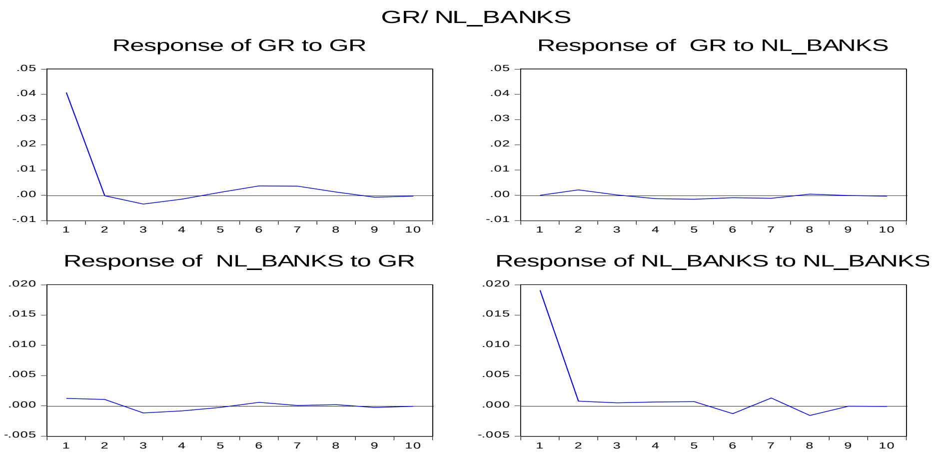
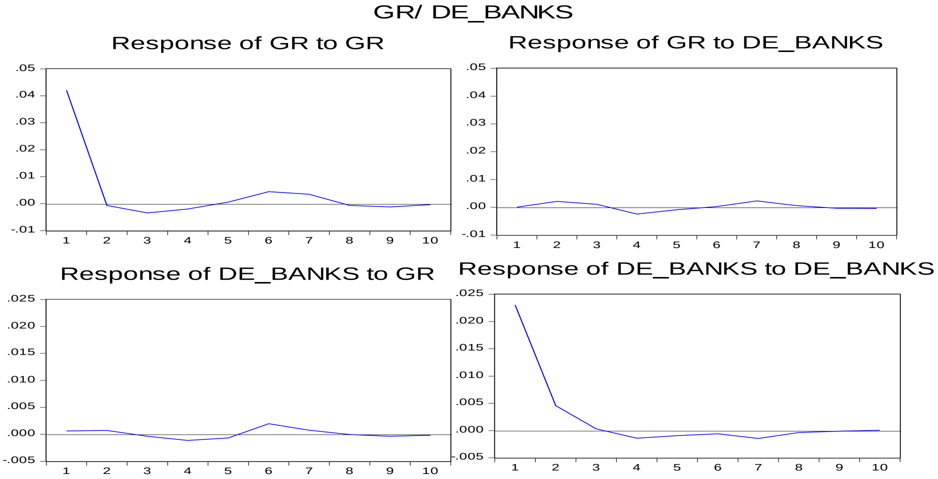
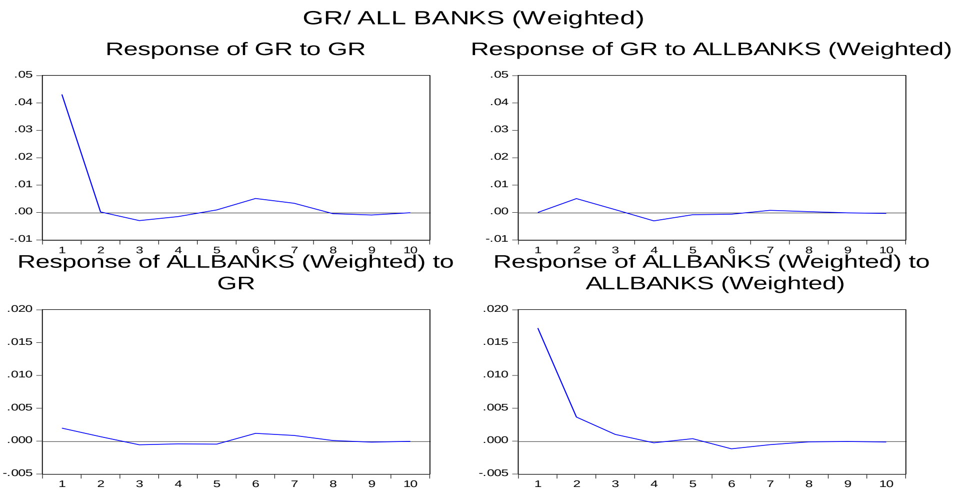








Note: The figures depict the impulse response functions for the sovereign and bank CDS spreads for the next 10 days after a shock to the estimated VAR or VEC model. Period 2 ranges from 27/10/2011 to 05/30/2014. X-axis denotes the number of days after the shock and Y-axis the response of a variable to a one standard deviation shock on the other variable.

Essay 1

Essay 2

Some thoughts on the external finance premium and the cost of internal finance

2.1. Introduction

The external finance premium is a key concept in the operation of the balance sheet channel of monetary policy transmission. This premium is the difference between the cost for firms of raising finance from external and from internal sources respectively; its existence signifies that these two types of finance are imperfect substitutes. If, on the other hand, internal and external finance were perfect substitutes, this would mean that any temporary differences in the cost of finance from these two sources would be arbitraged away and the Modigliani-Miller irrelevance proposition would hold. Somewhat surprisingly, the literature, including the paper that established the concept of the external finance premium (Bernanke and Gertler, 1989), defines this premium as the difference between the cost to borrowers of raising external finance and the opportunity cost of using internally generated funds, which is not the same as the cost of internal finance. When the cost of internal finance is defined in the ambiguous sense of the opportunity cost, internal funds are thought to have a cost advantage over external finance (Bernanke, 2007). In this study, we focus on the concept of the cost of internal finance and come up with an operational definition that distinguishes it from the opportunity cost of internal finance but also from the cost of equity capital, given that equity capital constitutes an external source of corporate finance. Specifically, we use the return on retained earnings to firm owners in order to measure the cost of internal finance. With the cost of internal finance properly defined, the external finance premium can no longer be characterized as a "premium" but is rather a cost differential between external and internal finance. As such, it still retains the countercyclical property of the external finance premium as defined in the literature, and can also be shown to be part of the specification of a financial accelerator mechanism similar to the one described by Bernanke et al. (1999).

The definition of the cost of internal finance in this essay brings us to another issue, seemingly unrelated to that of the external finance premium, namely the measurement of the equilibrium real interest rate. This issue has gained importance over the past decade when real interest rates showed an unprecedented decline after the global financial crisis of 2008-2009 and reached levels not seen before. Interest in the equilibrium rate derives from the fact that this rate provides a benchmark for measuring the stance of monetary policy; policy is expansionary (contractionary) if the short-term real interest rate is lower (higher) than the equilibrium rate (Holston et al., 2017).[1] However, the equilibrium real interest rate is a variable not directly observed and its measurement has proven a difficult task. This is particularly relevant today when the equilibrium rate has declined so much and the question whether the decline is permanent or not has arisen (Williams, 2017b).

Analysis based on US data endeavoring to estimate the equilibrium real interest rate is either based on single-variable methods or is model-based. The former focuses on long-run or steady state values, examining the behavior of the real interest rate over long periods of time (e.g. Hamilton et al., 2016). The interest rate is usually the rate on riskless assets, although some studies called for the use of interest rates on risky assets (e.g. Cukierman, 2016). Model-based studies use theoretical frameworks that are generally characterized by the absence of financial frictions, as in the case of various versions of the New Keynesian model. A popular model in this category of studies is the Laubach and Williams (2003, 2016) model. In this work, we follow the first approach to measure the equilibrium real rate, which is based on our definition of the cost of internal finance. The main idea is that the equilibrium real interest rate expressed in terms of the cost of internal finance can be obtained from the long-run

[1] With central banks also intervening in the longer end of the yield curve in order to provide monetary policy accommodation and with short-term rates bounded by an effective lower bound, short-term real rates are no longer considered to be sufficient summary measures of monetary conditions. To address this, the concept of "shadow rates" has been introduced (see Black, 1995 and Wu and Xia, 2016).

static model that corresponds to an otherwise standard dynamic macroeconomic model, for instance a New Keynesian type of model, extended to include financial market frictions. This rate can be considered as the hypothetical (real) cost of internal finance that would prevail in the long run after temporary shocks affecting the economy have died out. We show that this measure of the equilibrium real rate is equal to the ratio of the depreciation flow, i.e. the amount of earnings required to finance capital consumption in equilibrium, to the stock of retained earnings.

Section 2 discusses in depth the external finance premium as encountered in the literature, develops the concept of the cost of internal finance, and calculates the cost differential between external and internal finance. Section 3 extends the methodology used to define the cost of internal finance in order to derive a measure of the equilibrium real interest rate in terms of the cost of internal finance, and makes some comparisons with existing estimates. Finally, Section 4 concludes.

2.2. Facts and fallacies about the external finance premium

The concept of the external finance premium introduced by Bernanke and Gertler (1989) is central to the analysis of the balance sheet channel of monetary policy transmission.[2] Credit market, or, more generally, capital market imperfections, give rise to a difference between raising funds from external sources of finance (i.e. through loans, bonds or equity) as opposed to internal sources (i.e. through retained earnings). The cost differential is referred to as the external finance premium. According to Bernanke and Gertler (1995), agency costs underlie the external finance premium. For example, lenders cannot observe without cost the returns of the investment projects they finance but must incur a fixed audit or monitoring cost to observe those returns; in this respect, the "costly state verification" represents an agency cost. The fact that borrowers have better information about the characteristics of their projects or the ability to take unobserved actions that can affect the nature of the risk involved and its impact on the projects' returns can increase agency costs.

[2] A recent reformulation of the bank lending channel (Bernanke, 2007) posits that the external finance premium plays also an important role in monetary policy transmission through this channel, for banks who manage their liabilities.

The notion of agency costs is basic to the analysis of the relationship between the external finance premium and the firm's net worth.[3] Thus, due to agency costs, a lower net worth worsens the terms under which firms are able to raise external finance and also increases the external finance premium, which is in this way negatively related to net worth. This, in turn, implies a reduction of the net return to investment (Bernanke and Gertler, 1989). Many studies define the external finance premium as the difference between the cost of external finance and the opportunity cost of internal finance (e.g. Bernanke and Gertler, 1989; Serven and Solimano, 1992; Bernanke and Gertler, 1995; Bernanke et al., 1999), which is not the same as the cost of internal finance. Thus, there is a conceptual problem concerning the definition of the external finance premium. Later we shall try to address this problem by specifying the cost of internal finance not in the ambiguous sense of the opportunity cost.

The existence of a non-zero cost differential between internal and external finance implies that these two types of finance are not perfect substitutes. This differential arises due to financial market frictions or more generally capital market frictions. These frictions emerge when perfect trade in certain markets cannot take place (Quadrini, 2011). The idea is that markets are incomplete because parties are not willing to engage in certain trades because there is limited enforcement of contractual obligations for reasons such as information asymmetry. This is an agency problem. For example, the information asymmetry limits the ability of shareholders of a firm to force corporate management to maximize the firm's net worth when this management uses retained earnings to finance investment projects of low expected returns.

If internal and external financing were perfect substitutes, the Modigliani-Miller theorem would hold, and the capital structure would be irrelevant for investment decisions as it would not matter whether acquisitions of capital are financed by entrepreneurial wealth (net worth) or borrowing: the cost of financing from different sources would be the same. If, however, different types of finance are imperfect substitutes, the firms would face a cost differential when raising finance from different sources. Moreover, capital investment decisions and capital structure decisions would no longer be unrelated.

[3] Bernanke et al. (1999) specify net worth as the "borrowers' liquid assets plus collateral value of illiquid assets less outstanding obligations". Operationally, Bernanke and Gertler (1995) define it "as the sum of liquid assets and marketable collateral".

The ambiguity regarding the definition and measurement of the external finance premium is reflected mainly in two aspects. First, external finance is asserted to be virtually always more expensive than internal finance, which involves internally generated cash flows, because lenders incur costs of evaluating borrowers' prospects and monitoring progress regarding the implementation of investment projects (Bernanke, 2007). Thus, the external finance premium is generally positive. Second, a number of indicators are used for the measurement of the external finance premium. Gertler and Lown (1999) use for the U.S. the spread between the high-yield corporate bond rate and the corresponding rate for the highest quality firms (AAA rated) or the rate on ten-year Treasury bonds. Similarly, Mody and Taylor (2004) measure the external finance premium as the difference between the Merrill Lynch high yield bond index and the 10-year government bond yield. Krylova (2016) constructs various corporate bond spread indices, and also spreads between lending rates, for firms with different credit qualities, for the Euro area and five major European economies. Recourse to indicators or proxies for the external finance premium reflects the view that it is difficult to obtain direct measures of the premium (Bernanke and Gertler, 1995). Some authors go as far as to say that the external finance premium is unobservable (e.g. De Graeve ,2008). Gertler and Lown (1999) qualify the view that the premium for external funds is not easy to measure by noting that plausible indicators for this premium should preferably be market determined: until the development of the market for high yield debt in the U.S., such indicators did not exist, while the only available interest rate to use in aggregate time series analysis for borrowers who traditionally rely heavily on commercial banks for external finance is the prime lending rate, which is a posted rate. However, possible measurement problems surrounding the external finance premium do not invalidate in any way the conceptual distinction that was drawn here between the cost and the opportunity cost of internal finance.

How, then, is the cost of internal finance going to be properly defined and measured? To address this question, we recall that retained earnings is that part of net cash flow generated by a firm's past investments that is retained within the firm rather than being distributed to shareholders as part of the dividend flow. Because retained earnings arise from sources internal to the firm, rather than external sources such as new equity issues, there is a temptation to believe that this source of finance is somewhat costless. In fact, retained earnings belong to the shareholders of the company and so the cost of retained earnings or, alternatively, the return these earnings are expected to generate should be related closely to the return required by shareholders on new equity. We can now define the cost of retained earnings by noting that this cost is really the return on retained earnings (whether we choose to call it a "cost" or a "return" is a matter of perspective). The return on retained earnings in a given period can be seen to have two components (see Table 2.1): (a) the flow of retained earnings (ΔRE) in the period, where RE is the stock of retained earnings, and (b) the depreciation flow, i.e. the amount of earnings required to finance capital consumption of the period (DEP). The latter are already deducted from accounting measures of net earnings and therefore need to be added back to the flow of retained earnings as they represent the minimum return the firm, as a going concern, has to deliver in order to maintain its physical capital stock in operation. The sum of these components as a percentage of retained earnings gives the (real) cost of retained earnings for the firm:

$$\varphi = (DEP + \Delta RE)/RE \qquad \textbf{(2.1)}$$

Given the cost of retained earnings φ, firms make their financial decisions on the basis of their relative capital structure. It is useful at this point to reiterate that if internal and external finance were perfectly substitutable, the capital structure would be both indeterminate and irrelevant to real decisions. The cost of capital would be the same regardless of the financing method. When, however, we allow for capital market imperfections, the question of investment financing is relevant, and a number of factors should be considered when evaluating different sources of finance. Whatever the outcome, it is difficult to identify in a simple way the optimal capital structure. This should not detract us from the fact that, with a changing capital structure, two interrelated decisions are involved: a capital investment decision and a capital structure decision. To illustrate this, we note that the stylized model proposed by Bernanke and Blinder (1988) for analyzing the bank lending channel and estimated for six major economies by Brissimis and Magginas (2005)[4] explicitly incorporates

[4] Bernanke and Blinder (1992) did not attempt a structural estimation of their model but instead applied a VAR model to US data to examine the impulse responses of a number of macroeconomic variables to an innovation in the Federal funds rate.

the interdependence between changes in financial structure and investment demand (and thus output demand).

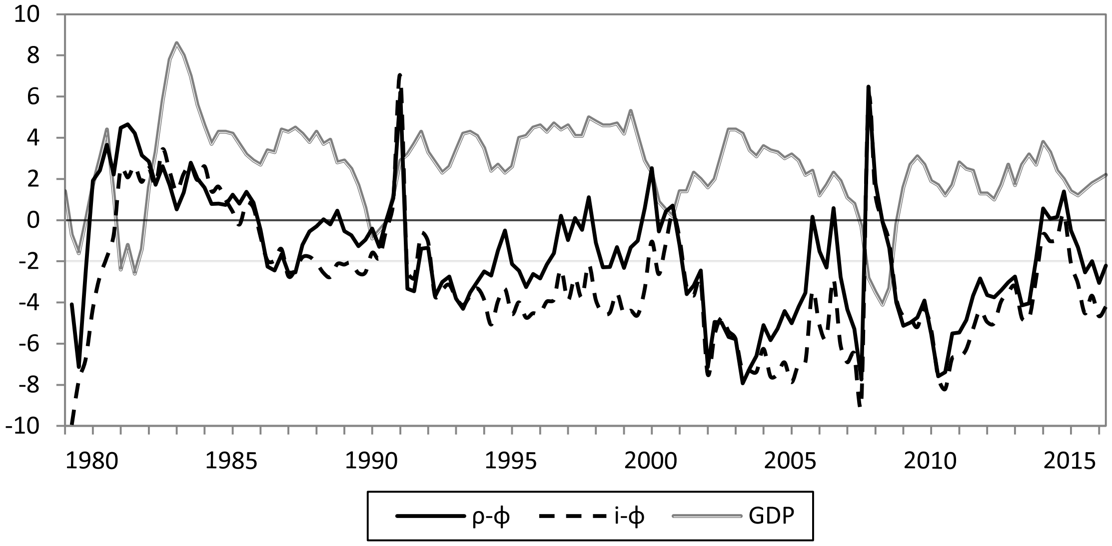
Table 2.1 Firm's capital structure

Type of finance	Provider of finance	Cost of finance/ Rate of return (real)	Borrower
Internal finance			
Retained earnings (RE)	Stockholders/ Firm owners	(DEP + ΔRE) / RE	Management/Firm
External finance			
Equity (E)	Stockholders/ Firm owners	DIV / E	Management/Firm
Loans (L)	Banks	$i^L - \Delta p$	Management/Firm
Bonds (B)	Bondholders	$i^B - \Delta p$	Management/Firm

Note: Definition of variables: DEP: depreciation (flow); RE: retained earnings (stock); Δ: first-difference operator; ΔRE: retained earnings (flow); DIV: dividends; E: stockholders' equity; i^L: bank lending rate; p: price level (log); i^B: bond rate.

With a mixed capital structure, where all forms of capital are held in varying proportions, it is the weighted cost of capital that affects real investment decisions of firms. On the other hand, the internal and external financing mix depends inter alia on the cost differential of different sources of finance. Figure 2.1 below shows the evolution of two alternative measures of this relative financing cost. One is the spread between the real bank lending rate and the (real) cost of retained earnings as specified above (eq. 2.1) and the other is the spread between the real bond rate and the above cost of retained earnings. Both spreads mostly take negative values, with the exception of the four US major recessions in the last forty years: the 1981-1982 recession, the recessions of the early 1990s and early 2000s and, finally, the Great Recession of 2008-2009. Thus, these differentials could hardly be characterized as 'premia' on internal finance. They would rather represent cost differentials between external and internal finance.

Figure 2.1: Cost differentials and GDP growth (1980:Q1-2017:Q2)



Note: GDP: real GDP growth rate (annual %), ρ-φ: real cost differential between loans and retained earnings, i-φ: real cost differential between bonds and retained earnings.

Source: FRED and QFR databases and authors' calculations.

However, both the external finance premium as defined in the literature, and the cost differential between external and internal finance as specified in this essay, share a common feature. Specifically, they both display countercyclical behavior. In our setting, an increase in the cost of internal finance relative to that of external finance lowers, ceteris paribus, the demand of firms for retained earnings and, to the extent that these retained earnings are procyclical, the cost differential between external and internal finance will be countercyclical. The countercyclical behavior of the cost differential is evidenced in Figure 2.1, which shows, together with the two measures of the cost differential, the annual growth rate of GDP. Furthermore, the procyclicality of firms' retained earnings, which is partly associated with countercyclical variations in the above cost differentials, is expected to lead to the operation of a financial accelerator mechanism similar to that described by Bernanke et al. (1996, 1999).

2.3. Measuring the equilibrium real interest rate in terms of the cost of internal finance

A useful extension of the logic used in this study to define the cost of internal finance would be to follow an alternative methodological approach in order to derive a measure of the equilibrium real interest rate based on asset returns data. The equilibrium real interest rate (or natural rate of interest) is usually defined as the real interest rate that is consistent with full utilization of resources in the economy and price stability. It is often measured as the hypothetical real rate that would prevail in the long run once all of the shocks affecting the economy die out (Fischer, 2016). The long run is a period of sufficient length to enable all markets to clear, and to allow all variables in the economy to settle at constant levels in the absence of new economic disturbances. Thus, in long-run equilibrium, the economic system must satisfy the condition that all variables should be time invariant, i.e. stocks should remain constant and flows should perpetuate themselves at the same level. Equation (2.1) will be the starting point for calculating the equilibrium real interest rate. In equilibrium, this equation becomes:

$$\varphi^* = DEP/RE \qquad \textbf{(2.2)}$$

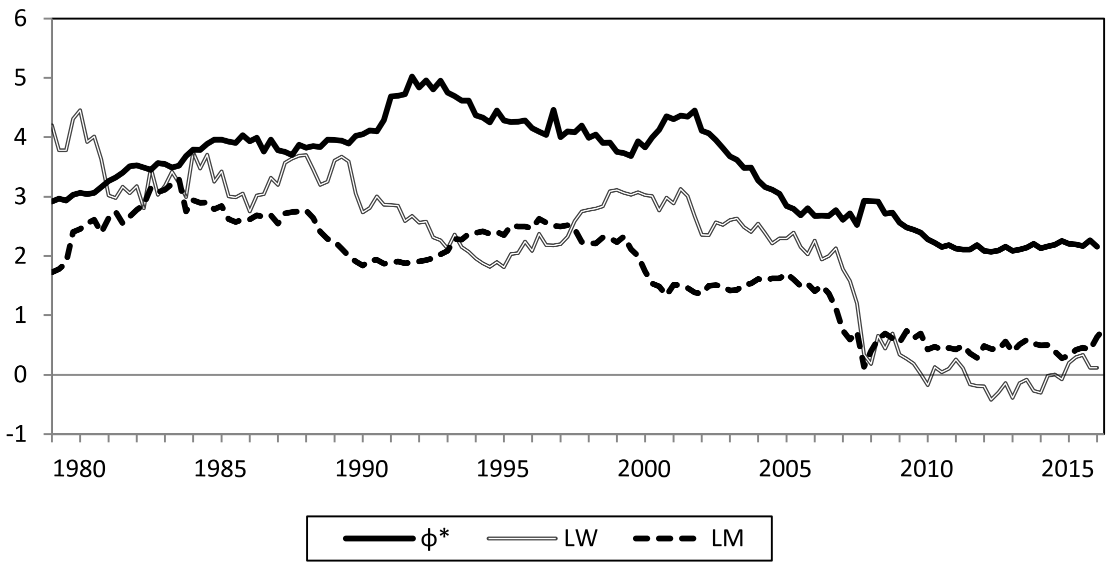
since equilibrium implies that the stock of retained earnings remains constant and there is no flow of retained earnings. The intuition behind equation (2.2) is that in the stationary state, there are additions to capital in each period, which are balanced by an equal consumption of capital (depreciation), so that the stock of capital remains fixed.

In equation (2.2) we focus on the steady state values of the real interest rate, by examining the behavior of the (real) cost of internal finance variable over a period which, as indicated, is sufficiently long (actually it extends to infinity) to allow the effects of shocks to die out. Cukierman (2016) suggested that increasing attention should be paid to the long-term risky interest rate and therefore to the natural counterpart of this rate, since existing estimates of the natural rate, which are based on riskless assets, are likely to be biased downward. Also, Hamilton et al. (2016) state that the equilibrium real interest rate based on the federal funds rate is distinct from the equilibrium real rate of return on business capital, equities, long-term government debt, or short- or long-term consumer or corporate debt, although those returns are expected to be related to the equilibrium real federal funds rate.

If we were to follow a model-based approach in order to obtain a measure of the equilibrium real interest rate, the model would probably have to be an otherwise standard macroeconomic model extended to include financial market frictions. The models used to analyze the equilibrium real interest rate are mostly based on the New

Keynesian paradigm. This type of model, however, suggests that we are in a Modigliani-Miller world where markets are complete and the financial structure does not matter – it is in fact indeterminate. The only interest rate that is defined in such a model is that on monetary assets. However, research, especially after the financial crisis, has shown that the complete markets assumption has some limitations and should be modified to take into account a changing financial structure.

Figure 2.2: Equilibrium real interest rates



Note: φ*: equilibrium real interest rate based on eq. (2.2), LW: the Laubach and Williams (2016, updated) real equilibrium real interest rate, LM: the Lubik and Matthes (2015, updated) equilibrium real interest rate.

Source: Laubach and Williams (2016) and Lubik and Matthes (2015) estimates; QFR database and authors' calculations.

In Figure 2.2, we plot the equilibrium real rate computed from equation (2.2) for the period extending from the first quarter of 1980 through the second quarter of 2017. The time evolution of the series shows a declining trend from a high of 5 percent in the early 90s toward values hovering around 2 percent in the more recent period. This pattern is consistent with the decline of the equilibrium real interest rate estimated in other studies.

Is it reasonable to suggest that the equilibrium real interest rate has declined in the above period? Summers (2014) discussed a number of factors that may have contributed to the decline in the equilibrium real interest rate. One such factor may be the reduction in demand for debt-financed investment following a period of excessive leverage. Another factor is the increase in corporate retained earnings, which led to an increase in the level of savings. Furthermore, the persistent slowdown in productivity growth, combined with demographic shifts, may have led to slower growth in potential output. Future slow growth discourages current investment and, on the other hand, may provide to households an incentive to increase saving (Liu and Tai, 2016). The larger supply of funds available through savings and the lower demand for funds to use for investment seem to operate in the direction of a lower equilibrium real interest rate.

Figure 2.2 also shows for comparison two other measures of the equilibrium real interest rate (federal funds rate) from two studies that employ model-based methods to estimate this rate. The Laubach and Williams (2016, updated) study relies on a small-scale empirical model that has some underpinnings in the New Keynesian model of the economy. The Lubik and Matthes (2015, updated) study, on the other hand, takes a less structural approach by applying a time-varying VAR model to the data. A common finding in these studies is that the equilibrium real interest rate shows a downward-sloping trend reaching in recent years a level not seen in decades. Also, a notable finding of the second study is that the estimate of the equilibrium rate never turns negative, while in the first study this rate entered negative territory in the early 2010s. However, given the considerable uncertainty surrounding the two estimates, any observed differences between the two series are hardly significant (Lansing, 2016). If we further compare these two estimates with our measure of the equilibrium real interest rate φ^* (eq. 2.2), the first thing we notice is that our series is uniformly higher than the other two, the difference between them being around 2 percent in the last seven years. We should stress that, along the lines of Cukierman (2016) and Hamilton et al. (2016), our measure should be seen as referring to the equilibrium risky rate, which presumably explains why it is higher relative to the above two measures of the equilibrium rate. Estimates of a similar order of magnitude to ours, at least for the most recent period, were derived by Taylor and Wieland (2016), who extended the period of estimation of the Smets and Wouters (2007) New Keynesian DSGE model of the US economy to the present and reported a value of the long-run equilibrium rate of interest that is somewhat above 2 percent. They suggested that the Laubach and Williams (2016) estimates are downward biased because some key determinants are omitted from their estimating equations and also their model does not include a financial sector, its omission being of no less importance.

Given the variety of factors that have pushed the equilibrium real interest rate to a very low level, the question is whether we have moved to a permanently lower long-run level, since to date there are no signs of a return to historically more normal levels. Williams (2017b) argued that the factors responsible for the decline of this rate appear poised to stay that way. The major one is that the growth rate of potential output has slowed down to around 1.5 percent, reflecting sharp declines in labor force growth and lower productivity growth. The low estimates of the equilibrium real interest rate have not been influenced solely by US-specific factors but instead longer-term global influences are at work affecting the global supply and demand for savings (Williams, 2017a; Holston et al., 2016).

The broader implication of the permanently lower equilibrium real interest rates is that monetary policy has not much room to stimulate the economy in downturns of the cycle and there is need to rely more heavily on unconventional measures keeping interest rates very low for a long time (Williams, 2017b; Reifschneider, 2016).

2.4. Conclusions

The external finance premium, defined as the difference between the cost of capital raised by firms from external sources and of capital raised internally, plays a distinct role in the operation of the balance sheet channel of monetary policy transmission and of the financial accelerator mechanism enhancing monetary policy effects. However, as pointed out in this essay, there is a conceptual problem, which has not been brought out in the relevant literature regarding the definition of the external finance premium, namely that the cost of internal finance in that definition is convoluted with the opportunity cost of internal finance, which is not the same as the cost of internal finance. In this study, we drew that distinction and specified the cost of internal finance as the (real) return on retained earnings to firm owners, which is a cost if viewed from the firm’s side. When the external finance premium is rightly measured as the cost differential between external and internal finance, it can hardly be called a premium on internal finance. However, this measure is seen to retain the countercyclical property of the external finance premium as defined in the literature, and its role in a financial accelerator mechanism is similar to the one proposed by Bernanke et al. (1999).

Further, our work has dealt with the notion of the equilibrium real interest rate and proposed a new measure for this rate based on our definition of the cost of internal finance. This measure is the hypothetical real rate that would result in the long run after all markets in the economy have cleared and all variables have settled at constant levels in the absence of new economic shocks. In line with other estimates of the equilibrium real interest rate, our measure is found to display a declining trend since the early 90s and reach a low level around 2 percent in the past decade, but to remain consistently higher than the popularized Laubach-Williams (2016) estimate. If we were to use a model-based approach for estimating the equilibrium real interest rate, a model structure that would give us the new defined measure of the equilibrium rate--as well as its relationship to other equilibrium real rates of return, such as those on short-term monetary assets, equities or corporate debt--would be one in which the complete markets assumption is relaxed and financial market imperfections are admitted.

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Essay 3

Is it the bank lending channel, the balance sheet channel or both or neither?

3.1. Introduction

The recent subprime mortgage crisis of 2007 that evolved into a global financial crisis after 2008 has highlighted the importance of capital market imperfections, due inter alia to the existence of information asymmetries, for investment decisions. These imperfections contribute to the reinforcement and propagation of the adverse effects of monetary shocks on aggregate economic activity, by causing significant variations in firm's investment policy and short-run output. This in turn could cause negative effects on the real economy. Under conditions of imperfect capital markets, alternative forms of external finance (loans and bonds) are considered as imperfect substitutes for firms and/or banking institutions, while internal finance (retained earnings) and external finance (equity, bonds, debt) are considered as imperfect substitutes for borrowers. These conditions reinforce the effects of monetary policy changes on aggregate demand, beyond the effects that are attributed to the conventional interest rate channel.

In the early stages of the relevant empirical literature, many researchers tried to ascertain how monetary policy affects the real economy based on the operation of the monetary transmission mechanism. They studied how real output reacts to changes in short-term interest rates -caused by monetary authorities- by using only the neoclassical cost-of-capital variable.[1] This mechanism describes the operation of the interest rate channel, where variations in the cost of capital or user cost of capital are used in order to interpret the effects of the monetary policy makers' actions on aggregate demand.

In recent years and especially during the last crisis period, monetary policy actions focused on the operation of financial markets. The financial crisis led to a series of structural changes in the financial system with significant effects on the operation of the non-neoclassical transmission channels of monetary policy. Through the operation of the credit channel, on which we focus in this essay, variations in the financial conditions of borrowers have significant effects on investment and real output. Thus, we can capture the effects of the financial crisis on the real economy, beyond the restrictive effects caused by changes in the risk-free short-term interest rates.

Specifically, our aim is to examine how changes in monetary policy influence borrowers' investment decisions, particularly during the pre- and post-crisis periods. For this purpose, we examine the operation of the credit channel, which is disentangled into two components: the bank lending and the balance sheet channel. Through the operation of these two transmission channels, the effect of a monetary policy shift on investment and subsequently on real economy is magnified. A monetary tightening restricts the level of deposits, which in turn decreases the bank lending volume. In this case firms, which have strong links with banks for their finance, will face difficulties to find alternative sources of finance due to the existence of credit market imperfections (bank lending channel). On the other side, a monetary shock that leads to changes in interest rates, worsens financial conditions of borrowers and increases the wedge between the cost of external and internal finance (cost differential), which reduces loan demand. This mechanism (balance sheet channel) reinforces the initial effects on aggregate economic activity.

During the last two decades, financial innovations in international financial markets have decisively contributed to an efficient use of available funds by firms and have changed the necessary conditions for the operation of the credit channel. Also, a number of recapitalizations and liquidity support programs were necessary during the

[1] The cost-of-capital is defined in the literature as the weighted average cost of capital from all sources (debt and equity).

recent economic downturn period. The existence of new sources of funding for banking institutions (e.g. certificate of deposit, commercial paper), which offset possible reductions in deposits, have weakened the potency of the bank lending channel. In addition, alternative financial instruments in credit markets have decreased large variations in borrowers’ net worth, thus reducing the effectiveness of the balance sheet channel. Because of the greater availability of funds and easier access to them, the cost of external financing for firms has been reduced. This gave them the opportunity to place their funds in new investments and expand their activities.

The operation of the credit channel has been the subject of controversy in the empirical literature. For the existence of the bank lending channel, it is necessary that a monetary shock should have significant effects on the supply of bank loans. Banks' role in supplying credit to the real economy is critical in this respect. Thus, after a tightening of monetary policy, banking institutions reduce their reservable deposits and, as a consequence, they reduce credit supply, which implies negative effects for economic activity. Monetary policy actions could affect bank loan supply, and as a result the operation of the bank lending channel, through changes in the interest rates or in the level of bank reserves.

The balance sheet theory aims to specify the monetary transmission mechanism, through which an exogenous monetary shock is amplified and diffused with significant effects on firms' investment policy, because of the existence of credit market imperfections. The balance sheet channel emphasizes the impact of changes in monetary policy on borrowers' balance sheet conditions through the resultant changes in the cost differential between external and internal finance. A contractionary monetary policy causes a rise in interest rates, a decrease in the demand for capital as well as in investment spending and the price of capital. This in turn reduces firm’s net worth because debt obligations escalate, and also lowers the value of assets that can be used as collateral. Subsequently, it reinforces its need for external financing, which is necessary for the firm to apply its investment policy. As a result, firm’s cost differential and agency costs rise, with significant negative effects on firm’s net worth, demand for capital, investment and total output, once again. Thus, the negative effects of a monetary policy shift on borrowers' financial conditions and as a result on their investment spending are magnified via the financial accelerator mechanism (see

Bernanke and Gertler, 1989; Bernanke et al., 1996,1999; Gertler and Kiyotaki, 2010, among other studies), which operates through its impact on borrowers' balance sheets and the aggregate adverse effects on the real economy.

Due to the problem concerning the direct estimation of the external finance premium, -defined in the literature as the difference between the cost of external finance and the opportunity cost of internal finance- and the difficulties to specify if variations in the borrower's level of investment are attributed to changes in credit supply or in credit demand when using aggregate data, many recent studies utilize firm-level data, in order to capture the operation of the balance sheet channel. They include in a reduced-form investment equation a quantity variable which reflects firms' balance sheets conditions, in order to estimate the effects of a monetary policy change.[2] However, the main argument against this methodological approach concerns the endogeneity issues that may be caused by the different variables which are employed for firms' classification (e.g. see Schiantarelli, 1995). Our approach avoids the criticism about the direct estimation of the external finance premium by specifying an operational definition of the cost of internal finance (see Essay 2), as well as the problems that arise due to classification issues. We develop a model in order to assess theoretically the magnifying effects of a monetary policy shift on real economic activity when both the bank lending and balance sheet transmission channels are in operation.

Many studies try to specify if changes in credit aggregates after a monetary policy change arise from shifts in the demand for credit (balance sheet channel) or from shifts in the supply of credit (bank lending channel). We aim to capture both loan demand and supply effects, so as to address this identification issue. Bernanke and Blinder (1988) provide the necessary theoretical background for our methodological approach -they test only the operation of the bank lending channel. To our knowledge, this is the first study in the relevant literature aiming to identify the operation of the bank lending and balance sheet channels, simultaneously, both theoretically and empirically.[3]

[2] Chirinko et al. (1999) argue that because of simultaneity bias, the estimation results of the relationship between investment and the user cost of capital are very weak.

[3] Brissimis and Magginas (2005) use a similar methodological approach to examine the operation of the bank lending channel alone.

In our work, we try to address a number of interesting questions. What are the conditions for the non-operation of the bank lending and/or the balance sheet channels? Are the basic transmission channels of monetary policy -bank lending, balance sheet and interest rate channels- operational in the periods before and after the financial crisis in the U.S.? How can we assess the possible magnifying effects of the components of the credit channel after a monetary shift? In contrast to other approaches, in our theoretical specification, the existence of imperfect substitutability between alternative external sources of finance, and also between internal and external sources of finance are the basic assumptions for the identification of the two components of the credit channel (bank lending and balance sheet channels) which works complementary to the operation of the interest rate channel and amplifies the effects of a monetary shift on total output.

By applying the Johansen cointegration approach, we seek to examine the existence of the bank lending and balance sheet channels in the U.S during the period from 1994:Q1 to 2017:Q2 by specifying the loan demand and supply influences and also the demand for internal finance by firms. By using the methodological approach developed by Pesaran and Shin (2002), we pursue to identify cointegrating relationships by imposing and testing a number of appropriate over-identifying restrictions according to specific theoretical assumptions, which are linked to the operation of the monetary transmission channels. In case we identify three cointegrating vectors, the bank lending and balance sheet channels will be operative in addition to the interest rate channel. The specification of two cointegrating vectors signifies the operation of the balance sheet channel only. Finally, if we find only one cointegration relationship, then none of the two sub-channels of the credit channel is in operation.

Our empirical work is structured as follows. In a first step, we estimate a VAR model for the whole sample period, and perform the necessary tests for statistical adequacy and the Johansen test for cointegration among the variables. We split the sample period based on recursive and breakpoint stability tests in the parameters of the cointegrating vectors and in the system as a whole. We re-run the above tests in each subperiod. In a second step, based on the Johansen test results, we model the long-run relationships using cointegration techniques, through a VEC model. We set and examine a number of specific linear restrictions that hold when there is perfect substitutability between the different sources of external financing (specifically loans and bonds) for borrowers and/or banks and between the sources of external and internal finance for borrowers, in order to identify the equilibrium relationships included in our model according to the theoretical assumptions and test the long-run behavior of the variables.

A structural breakpoint is specified in the fourth quarter of 2008 and coincides with the spread of the US financial crisis around the world. Based on Johansen test results, only two cointegrating vectors are identified in both subperiods. Thus, our empirical results reveal that only the interest rate and the balance sheet channels are operational in the whole sample period in the U.S.. There is no evidence for the operation of the bank lending channel in both subperiods, as we find that there is perfect asset substitutability for borrowers and banks. This could be justified because of the stronger relationship between banking institutions and financial markets in the last decades, which provided alternative financial instruments (e.g. securitization, covered bond and credit default swaps markets) and reduced credit supply effects after a monetary policy shift. Also, the significant support to the banking system, through equity injections, debt guarantees and new loans by the US government at the end of 2008, contributed to limiting the adverse effects of a monetary shock during the crisis period.

The main contribution of this work to the existing literature is threefold. First, it provides an alternative theoretical model, based on the Bernanke and Blinder (1988) model which is extended to incorporate imperfect substitution between internal and external finance of firms. This permits to test simultaneously the operation of both the bank lending and the balance sheet channels. For this purpose, a new methodological framework is set. In particular, we specify a Vector Error Correction (VEC) model, and derive the cointegrating relationships according to this model, and test a number of appropriate restrictions that are necessary for the existence of perfect asset substitutability. Second, we specify analytically the amplifying effect of a monetary policy shift through the operation of the bank lending and/or the balance sheet channels. The effect of a monetary policy change on total output is greater when the three transmission channels are in operation simultaneously, relative to the case where only the balance sheet channel or none is operational. Third, this study allows to examine empirically if the structural changes observed in the financial markets over the last twenty five years, the financial deregulation in the banking system and the unconventional monetary policy measures that were enacted during the recent global financial crisis have limited the operation of the credit channel.

The rest of this essay is organized as follows. Section 2 provides a detailed overview of the operation of the balance sheet and bank lending channels and reviews the existing relevant literature. Section 3 develops the theoretical model which is used to examine the operation of the above two transmission channels, individually, and calculates the amplifying effects on real economic activity after a monetary policy change, due to the operation of the two channels. Section 4 discusses a series of stylized facts that took place in the U.S. during the recent crisis period and could have significant influence on the operation of the balance sheet and bank lending channels. Section 5 reformulates the theoretical model in a suitable form for empirical testing, displays the empirical approach, describes the data and presents the empirical results. Section 6 summarizes the main findings and offers concluding remarks.

3.2. The credit channel

The global financial crisis of 2007-09 stressed the role of the monetary policy transmission channels. The interest rate channel is the basic channel for the transmission of monetary policy. Monetary policy actions that cause changes in short-term real interest rates imply a variation in the cost of capital (or user cost of capital) and in borrowers' cash flow, which in turn lead to changes in their investment policy and in consumers' durable expenditure. Subsequently, a change in aggregate demand and overall output follows. Although, monetary policy actions may also affect the cost of capital through the operation of the credit channel, which captures both the demand side and the supply side of the credit market. The credit channel operates complementary to the interest rate channel, and not independently, as a separate part of the monetary transmission mechanism. Its function contributes to the amplification of a monetary policy effect through changes in credit supply. The basic idea of the operation of the credit channel is that information asymmetries[4] between borrowers

[4] The absence of information asymmetries implies that borrower's investment will be determine only by its investment opportunities (demand side) and the cost of capital.

and lenders, which arise because of the presence of financial frictions, enhance the impact of shifts in monetary policy on interest rates.[5]

The different sources of finance, the different cost between internal and external finance because of the existence of agency costs, and the different characteristics among borrowers are some issues that are stressed in the study of the credit channel. The credit channel consists of two independent channels, the bank lending channel and the balance sheet channel.[6] The bank lending channel emphasizes changes in the supply of bank loans after a change in monetary policy. On the other hand, the balance sheet channel underlines the consequences of a monetary policy change in borrowers' balance sheets. A prerequisite for the operation of the bank lending channel is the imperfect substitution between forms of external financing, for banks and/or borrowers, while for the balance sheet channel the imperfect substitution between internal and external financing, due to the existence of incomplete financial markets.

There is a direct relationship between the two channels. An increase in the interest rates exacerbates banks' balance sheets, since it reduces the value of their securities and, consequently, limits banks' ability to provide loans to firms, due to the existence of credit market imperfections. This in turn raises the cost differential[7] between external and internal finance, and, has direct consequences for borrowers' balance sheets, especially for those who are more dependent on bank loan supply, while borrowers' access to new financing is limited (balance sheet channel). Under these conditions, borrowers are obliged to use internal finance in order to be able to meet their obligations. A subsequent decrease in bank deposits, combined with the possible existence of liquidity constraints that prevent the replenishment of the funds of banking institutions -as happened during the recent financial crisis- provoke a decrease in bank loan supply (bank lending channel).

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[5] Monetary transmission channels are categorized in two different types; neoclassical and non-neoclassical channels. In the first type there are no financial market imperfections, while the level of investment is specified only by economic fundamentals. In the second, financial markets are imperfect and financial variables have significant effects on investment spending, due to the existence of information asymmetries. The credit channel is included in the second type of channel.

[6] The balance sheet channel is also called broad credit channel (e.g., Oliner and Rudebusch, 1996; Chatelain et al., 2001), while the bank lending channel is also labeled as narrow credit channel (e.g., Gambacorta and Marques-Ibanez, 2011).

[7] The cost differential is identical with the external finance premium, which is used extensively in the relevant literature, when the cost of external finance is greater than the cost of internal finance.

So, while the bank lending channel is responsible for the effects of a monetary policy action on the supply of bank loans, the balance sheet channel has a corresponding impact on borrowers' loan demand. Therefore, the credit channel accentuates the role of credit for the conduct of monetary policy and seeks to determine the additional effects of the above two channels on the operation of the interest rate channel. Thus, by examining its operation we can better understand how the real economy reacts to monetary policy shifts.

Beyond the studies which examine only the operation of the interest rate channel as a transmission monetary policy mechanism, there is a strand of literature that studies the bank lending and balance sheet monetary transmission channels, which are considered useful monetary tools and have significant effects on spending, investment and aggregate output. Bernanke and Blinder (1988), Gertler and Gilchrist (1994), Kashyap, Lamont and Stein (1994), Morgan (1998), among others, ascertain the operation of the credit channel, however, they do not specify the operation of each component independently.[8]

Bernanke and Gertler (1995) were the first who studied the operation of the two sub-channels separately. They argue that the empirical studies cannot explain the exact mechanism through which the monetary policy affects the real economy. They argue that these studies, which use neoclassical cost-of-capital variables, cannot quantify the cost-of-capital effects on aggregate spending. Furthermore, the composition of the spending effects on short-term and long-term assets is not clearly defined. In order to find answers to the above issues and specify the effects of monetary policy changes, Bernanke and Gertler (1995) base their study on the operation of the credit channel, and especially on the magnitude of the external finance premium.

De Bondt (1999) stresses that monetary policy affects the external finance premium through the operation of the bank lending and balance sheet channels. He uses a number of different proxies for credit market imperfections like the size of borrowers and lenders and the loan-deposit spread. The external finance premium, which arises

[8] Liu and Minford (2014) extend the standard New Keynesian model, in order to include the banking sector, which had a critical role during the recent crisis. They add the credit channel in order to find out how a banking sector is able to explain the recent US financial crisis. They provide evidence for the operation of the credit channel.

because of these imperfections, is defined as the difference "between the cost faced by potential borrowers and the expected returns received by lenders". He uses net financial wealth as a variable for firms' financial conditions. A negative variation in wealth causes a decrease in loan supply and an increase in the external finance premium. De Bondt (1999) uses a VEC model in order to determine credit supply and demand effects after a change in monetary policy. He seeks to identify the function of the bank lending and balance sheet channels by comparing cross-country differences in the financial structure. According to the author, the external finance premium fluctuates, vice versa, with borrowers' net worth and with a change in monetary policy. Thus, in this way monetary policy enhances its impact on investment spending.

Black and Rosen (2007) claim that a necessary condition for the operation of the credit channel is a series of changes in lending, which amplify a monetary policy shock. They separate it into the bank lending and balance sheet channels. They use loan level data and ascertain the operation of both sub-channels. They examine the relationship between spot lending and commitment lending in order to capture variations in the supply of bank loans to small and large firms separately. A reduction in spot lending relative to commitment lending indicates a reduction in loan supply. Moreover, changes in the supply of commitment loans are used as a proxy for changes in loan demand. This allows for the separation of changes in loan supply from the respective changes in loan demand. The bank lending channel works through changes in loan maturity, while the balance sheet channel works through a reallocation of short-term loan supply from smaller to larger firms, when there is a tightening in monetary policy.

3.2.1. Overview of the balance sheet channel

Modigliani and Miller's (1958) irrelevance proposition, considers that under certain restrictive assumptions,[9] a firm's capital structure does not affect its value. Modigliani and Miller argue that when there are perfect capital markets, firm's investment spending moves independently from its financing options (debt or equity). It does not

[9] Modigliani and Miller (1958) assume that there are no capital market frictions, such as transaction costs, and also there are no taxes, bankruptcy costs, and asymmetric information. Investors and firms borrow and lend at the same rate, while they are price takers, because there are conditions of perfect competition. Finally, they assume that debt financing has no impact on firm's earnings before interest and taxes.

matter which sources of finance firms will choose for its investments. But in case that market frictions exist, imperfect substitutability between internal and external finance is observed and therefore the above theory is not valid. Then, a wedge arises between the cost of external and internal funds. The larger this wedge is, the higher the financial constraints that firms will have to face for the realization of their investment plans are.[10]

Information asymmetries between borrowers and lenders -which in turn imply difficulties in the enforcement of new contracts-, agency costs,[11] monitoring costs and incentive problems for managers -when they do not have the absolute ownership of a firm-, are the main reasons for the imperfect substitution between internal and external finance. Bernanke and Gertler (1989), among others, have studied how the above factors affect borrowers' investment decisions. Information asymmetries are essential for the existence of imperfect substitutability between internal and external funds. They arise due to adverse selection problems in equity financing[12] -when lenders do not have full access in firm's inside information about its investment plans and financial position, whereas management does-, moral hazard problems which are apparent due to limited liability debt,[13] and credit rationing by lenders.[14] The higher these asymmetries are, the lower the substitution between internal and external funds becomes. This is because the gap in the cost of these funds is amplified. Thus, imperfect substitution between internal and external funds makes borrowers' financing decisions of critical importance.

Based on the literature, the external finance premium is defined as the difference between the cost of capital raised from external sources, i.e. equity, bond or debt

[10] Because of the existence of capital market imperfections, it may be difficult for a firm to have access in external sources of finance. In order to overpass the financial constraints, a firm is obliged to rely on its own funds to self-finance its investments. In this case, firm's investment decisions will be determined not only by the net present value of an investment project but also by the level of firm's available internal funds (balance sheet conditions).

[11] Agency costs can be attributed, among others, to the existence of coordination failure of credit markets (Goldstein and Pauzner, 2005 in de Groot, 2012), or to the costly state verification problem of borrowers, or to a potential hold-up (or commitment) problem for lenders (Hart and Moore in Kiyotaki and Moore, 1997).

[12] Greenwald (1984); Myers and Majluf (1984).

[13] Jensen and Meckling (1976).

[14] Stiglitz and Weiss (1981); Williamson (1987).

markets, and the cost of capital raised internally by retaining earnings.[15,16,17] This premium arises due to market frictions, which cause information asymmetries, as investors demand higher rates of return to hedge the relevant risk. The empirical literature is based on two critical assumptions. First, the cost of internal finance is lower than the cost of external, and second, there is a negative relationship between firm's net worth and the external finance premium. This negative relation arises due to the existence of capital market imperfections. Because there is a cost for lenders to overpass these imperfections, this cost will be passed over to borrowers. For this reason it is assumed that the cost of external finance is always greater than the cost of internal finance. This implies significant effects on borrowers' investment decisions. The higher the dependence on external financing is, the stronger the effects from the operation of the balance sheet channel are. This wedge is a result of the imperfect substitutability between internal and external sources of finance. A reduction in capital market imperfections decreases the wedge between the cost of internal and external funds, as the information asymmetries between borrowers and lenders become less severe. Many researchers, among them, Bernanke and Gertler (1989), Gertler (1992), Greenwald and Stiglitz (1993), Kiyotaki and Moore (1997), Schiantarelli (1996), Almeida and Campello (2007), Agca and Mozumdar (2008) and Guariglia (2008) have examined the dynamic effects of these imperfections, -through changes in the external finance premium - on business investment policy.[18]

Only a few studies in this field of research focus on how monetary policy shocks affect the level of investment spending, real output and aggregate economic activity, under conditions of imperfect capital markets. These shocks have direct consequences

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[15] Bernanke and Gertler (1995).

[16] According to Ćorić (2012), when information asymmetries between borrowers and lenders are solvable, the external finance premium is defined as: "the difference between the interest rate on the external source of finance that agents with low net worth would be charged compared to the interest rate those agents would be charged in the situation where their net worth is high". On the contrary, if the information asymmetries are not solvable the external finance premium is defined as "the difference between the marginal value of the firms' internal funds and the marginal costs of the external funds, and will contain the costs of all the wasted resources and missed production opportunities".

[17] The external finance premium is estimated inter alia in the empirical literature as the difference between the 6-month commercial paper rate and the 6-month T-bill rate, or as the difference between the prime lending rate and the 6-month T-bill rate.

[18] Bernanke and Gertler (1995) consider that the external finance premium is important for the interpretation of various problems encountered in the analysis of monetary transmission. For instance, the study of its behavior contributes to explain the delay observed in the reaction of inventories and nonresidential investment after a tightening of monetary policy.

on borrowers' financial conditions (net worth). The imperfect substitution between borrower's internal and external funds is the main impulse and the necessary condition for the operation of the balance sheet channel. This channel that operates complementary to the interest rate channel -due to credit market imperfections that generate financial constraints in firms' investment decisions- plays a distinct and crucial role for the implementation of monetary policy. The operation of the balance sheet channel can be illustrated as follows. An increase in the short-term interest rates, after a contractionary monetary policy, implies not only a decrease in the demand for capital and a resultant decrease in cash flow as the cost of capital rises for borrowers, but also a decrease in both equity prices and net worth. Furthermore, borrowers' asset prices decline and this causes a reduction in the value of collateral that they can use in order to increase their financing.

As a result, loan supply declines due to the amplification of adverse selection and moral hazard problems, and consequently, investment and aggregate demand also decrease. [19,20] Under these circumstances, borrowers do not have adequate capital and the required collateral that they could use in order to increase their external financing. Thus, they will have to pay higher external financing cost to lenders, so as to raise the external funds that are necessary for the implementation of their investment projects, in case their internal funds are insufficient. This rise in the cost differential is caused by the asymmetric information that increases the risk which creditors undertake. Thus, a negative relation between borrowers' balance sheets and the cost differential,[21] which influences investment spending, is observed.

The effects of a monetary contraction on borrowers' available credit are different, based on the different level of financial constraints that they face, while the latter are specified according to their balance sheet conditions. Thus, borrowers with lower net worth face higher credit constraints and larger financing costs, and, are obliged to reduce more their investment projects over the business cycle. So, under the operation

[19] Mishkin (1995).

[20] The consequences on aggregate economic activity will be more serious after a tightening of monetary policy for borrowers whose investment depends, to a great extent, on bank credit. According to Bernanke (1993) this may restrict their access to bank loans or raise the cost of bank credit, which in turn will reduce their investment expenditure to a greater extent.

[21] It is an essential condition that the cost differential will be contingent on borrowers' balance sheets. The theory shows that the external finance premium strongly depends on the firm's financial conditions during periods of recession.

of the balance sheet channel, the effects of a monetary policy disturbance on real economy will be more persistent and stronger due to the interrelationship between borrower's balance sheet conditions and the cost differential. The above procedure describes the operation of the balance sheet channel or the financial accelerator effect. There is no research according to which the notion of the balance sheet channel matches the notion of the financial accelerator effect. It is obvious that these notions capture identical mechanisms when a monetary shock occurs,[22] which contribute to the enhancement and propagation of this shock, through the balance sheet conditions of borrowers.[23] Consequently, the effects caused due to changes in the interest rates are amplified by changes in the cost differential. Thus, by using this differential, we are able to quantify the cost-of-capital effects beyond the restrictive neoclassical variable.

However, as it is described analytically in the previous essay of this thesis, there is a problem of conception, which has not been brought out in the relevant literature and concerns the definition of the external finance premium. This arises because the measures of the external finance premium are not clearly defined. Specifically, many studies consider the above premium as the difference between the cost of external finance and the opportunity cost[24] of internal finance, which is not the same as the cost of internal finance. To address this issue, in this thesis we use the return on retained earnings to firm owners in order to specify the cost of internal finance, not in the ambiguous sense of the opportunity cost. In this case, the basic assumption that the cost of external finance is always greater than the internal cost does not exist. Thus, the term "cost differential" instead of the "external finance premium" describes better the relation between external and internal finance.

Finally, the identification of the operation of the balance sheet channel is a controversial issue. Two basic different methodological approaches are followed in

[22] An economic shock that can affect borrowers' financial conditions and is the starting point for the financial accelerator effect could be except from a monetary shock, a technological shock, a productivity shock, a banking crisis shock, a shock in the labor market, or a government shock among others.

[23] Bernanke et al. (1996) were the first who introduced the "financial accelerator" term, while Bernanke and Gertler (1995) use the term "balance sheet channel", in order to describe the known procedure which was extensively employed in the empirical literature concerning borrower's investment policy.

[24] See e.g., Bernanke and Gertler (1995); Serven and Solimano (1992); Bernanke et al. (1999); Cohen-Cole and Martinez-Garcia (2009); Gertler and Kiyotaki (2010).

the literature. The first one investigates the interlinkages between the external finance premium and aggregate economic variables. The second one, by using disaggregated data, does not take into consideration the specification of the external finance premium. The sample is classified according to specific variables, which are used as proxies for borrower's financial constraints. Based on reduced-form equations, researchers test if variations on borrower's balance sheet conditions have significant effects on its investment in order to examine the operation of the balance sheet channel.

3.2.1.1. Methodological approaches for identifying the operation of the balance sheet channel

3.2.1.1.1. Identifying the operation of the balance sheet channel through the financial accelerator effect

There is a strand of studies in the empirical literature that examine the relationship between the external finance premium and aggregate economic indicators after an economic shock, assuming the existence of information asymmetries. The financial accelerator mechanism, which arises due to the existence of capital market imperfections, describes the procedure where a monetary tightening - a small initial economic shock in short-term interest rates- is magnified and diffused persistently to a significant and extensive shock with significant effects on real economic activity. There are a number of distinctive works in this field of research aiming to capture and describe the financial accelerator mechanism based on the external finance premium.[25]

Bernanke and Gertler (1989) were the first who developed a structural neoclassical growth “real business cycle” model in order to capture the financial accelerator effect. The formation of an external finance premium[26] creates a link between borrowers' balance sheet conditions (net worth) and real variables (investment, output), because of the information asymmetries between borrowers and lenders, assuming the

[25] A number of different partial-equilibrium models (Townsend, 1979; Greenwald, Stiglitz and Weiss, 1984; Kiyotaki and Moore, 1997) also examine the financial accelerator mechanism.

[26] Bernanke and Gertler (1989) assume that firms are able to overcome information asymmetries and have access to external financing by paying the external finance premium.

existence of a costly state verification problem (Townsend, 1979).[27] The existence of an inverse relation between economic agent’s net worth and external finance premium, after an economic disturbance, is the main axis for the operation of the financial accelerator mechanism. The negative relationship between borrowers’ financial conditions and agency costs magnifies the effects of an exogenous shock on borrowers’ investment. The higher the net worth is, the lower the agency costs and the external finance premium are, and consequently, the higher the firm’s investment spending is, and inversely.

An exogenous productivity shock weakens borrower's balance sheet (net worth) and amplifies the need for external financing due to the reduction of the internal cash flows. This in turn increases the external finance premium and reduces more the level of investment demand. The initial shock is strengthened because lower investment contributes to lower cash flows and lower economic growth in the following periods. Thus, there is a decrease in aggregate economic activity. Conclusively, credit market imperfections, which cause divergences between the cost of internal and external finance for borrowers, conduce to the reinforcement and propagation of an initial shock in the economy,[28] and so they are the main factors that provoke the financial accelerator effect. Bernanke and Gertler (1989) also provide evidence that the financial accelerator effect is stronger for borrowers with lower net worth (cash flows).

However, changes in net worth are caused not only by changes in borrowers’ cash flow, but also by changes in asset prices. Kiyotaki and Moore (1997), based also on a general equilibrium model, try to capture asset price effects on borrowers' net worth and production over the business cycle, in order to describe the "multiplier effects" (it is the same mechanism as the financial accelerator effect). They consider an economy where land is the only durable asset and serves a twofold purpose. It is used as a factor of production and as collateral for loans. The basic assumption of their model is that the financial constraints in a dynamic economy arise endogenously, due to the fact that only if debt is secured -through specific assets- borrowers are obliged to pay lenders back. Thus, information asymmetries between borrowers and lenders are

[27] According to the Townsend's costly state verification hypothesis lenders have to bear a cost in order to be able to audit borrowers, while this cost is transmitted to the financing cost of the borrower.

[28] A monetary shock is necessary in order to study the operation of the balance sheet channel.

difficult to be overcome. For this reason, borrowers are obliged to provide collateralized durable assets in order to have access to external financing, and secure the total amount of lending, an ability which is connected with their net worth.

A productivity shock restricts borrowers' balance sheets (net worth) because of a reduction in asset prices. Firms that face greater financial constraints are obliged to reduce investment spending that comprises investment in land. This, in turn, implies greater reductions in their net worth and in the level of investment in the subsequent periods. Consequently, Kiyotaki and Moore provide evidence that the dynamic interrelationship between asset prices and financial constraints contributes to the reinforcement and propagation of an initial small shock to technology or income distribution. The effects of these shocks on output and asset prices become larger and more persistent during time through the above multiplier process.

Contrary to the above studies, there is an approach that is not based on the external finance premium to describe the financial accelerator mechanism.[29] Greenwald and Stiglitz (1993) deploy a general equilibrium macroeconomic model for the same purpose. Based on the existence of financial market imperfections -due to adverse selection and moral hazard issues-, they show how these imperfections, which specify firm's stance toward risk, affect its investment. More specifically, they explain how production, labor inputs and investment change according to firm's risk taking behavior, which is determined by the net worth and the stock of liquid assets. Their main aim is to study how borrower's balance sheet conditions (net worth) affect its investment spending in order to interpret how a small economic shock can cause large and persistent effects among different firms over the business cycle. Thus, a shift in the supply curve of a firm leads to shifts in the demand curve of the other firms, reinforcing and propagating in this way the initial shock.

We observe that the previous studies capture the financial accelerator effect after a productivity shock. However, the financial accelerator model is used in order to capture the effects of capital market imperfections on the borrower's investment decisions and verify the operation of the balance sheet channel after a monetary

[29] Greenwald and Stiglitz (1993) show that the financial accelerator effect arises due to the existence of information asymmetries on equity markets -since a new equity issue implies a restriction on the share price of the firms because investors do not have the same information as management-, and on the behavior of firm's management which are risk averse because of personal interests. Thus, they assume that borrowers' financing options are based only on debt finance and not on equity finance.

shock.[30] Bernanke et al. (1996) aim to describe its operation, when a monetary shift occurs. They were motivated by the paradox fact that small shocks generate large cycles, and refer to this mechanism as the "amplification of initial shocks brought about by changes in credit-market conditions". Bernanke et al. (1996) stress the principal-agent problems, which exist in credit markets. They argue that endogenous changes in agency costs of lending, which arise because of informational asymmetries that are evident in credit markets between borrowers and lenders over the business cycle, contribute to the financial accelerator effect. More specifically, they use cross-sectional tests, in order to verify this accelerator effect. An indication of the operation of the financial accelerator is a greater reduction of the available credit for those borrowers who face higher agency costs, when a monetary policy shock occurs (firms with lower net worth bear higher variations in the cost of external financing in relation to those firms whose access to credit markets continues in a steady way). Therefore, the former are obliged to reduce their investment spending promptly, when there is an economic recession. This in turn amplifies the consequences of a monetary shock.[31] There is a "flight to quality" as Bernanke et al. (1996) mention.

Subsequently, Bernanke et al. (1999), in a more structural approach, develop a dynamic general equilibrium model in a closed economy with non-flexible prices, in which they include variables that capture credit market frictions that exist especially during stressed periods. This macroeconomic model allows for a better interpretation and quantification of potential large fluctuations in business cycles after a shock, due to the existence of credit market imperfections. They accept a costly state verification framework. According to Bernanke et al. (1999), the financial accelerator model aims to capture how endogenous variations in credit markets contribute to the reinforcement and spread of shocks to the real economy. They include "money and price stickiness" in their model, so as to specify the possible effects that imperfect credit markets have on the transmission of monetary policy actions. Also, they incorporate lag-values of investment, in order to capture the lead-lag relationship between firm's investment and asset prices, and they allow heterogeneity among

[30] Gertler and Gilchrist (1993), argue that nonlinear effects can be captured after a monetary policy change through the financial accelerator mechanism.

[31] Gertler et al. (2007) extend the Bernanke et al. (1996) financial accelerator model to an open economy with flexible exchange rates. Their main aim is to quantify the financial accelerator effect during a financial crisis.

borrowers so as to describe their access to capital markets. They claim that the external finance premium of a firm depends endogenously on its financial conditions.

More concretely, their model allows the specification of the interactions between the financial conditions of a firm and its investment behavior after a shock by including the external finance premium.[32] They assume that the external finance premium is negatively related to firm's net worth due to the existence of agency costs between borrowers and lenders. Procyclical variations in firm's net worth will cause countercyclical changes in the external finance premium over the business cycle. They separate the sample based on firms' accessibility to capital markets. They use changes in asset prices in order to capture the “multiplier effect”. A decrease in asset prices decreases borrowers’ net worth, which in turn increases the external finance premium. These conditions contribute to a decrease in borrowers’ investment and aggregate output. Afterwards, there is an accelerator effect through the subsequent decrease in asset prices and net worth that imply a new decrease in investment. The authors show that entrepreneurs with higher level of financial constraints (higher external finance premium) present higher investment sensitivity after a monetary policy shock, while the magnitude, persistence and diffusion of this shock in the real economy will be greater. Thus, they provide evidence for the operation of the balance sheet channel.

Hall (2001) employs a dynamic general equilibrium model that includes financial accelerator effects, in order to study the interrelationship between investment and financial conditions in the U.K. during business cycles. More specifically, he adapts the known Bernanke et al. (1999) financial accelerator model to the UK financial conditions, so as to examine the UK recessions. He runs the model with and without the financial accelerator mechanism being in operation. Additionally to the evolution of the bond spreads, he examines the financial accelerator mechanism in order to capture changes in the supply of finance, in relation to changes in the demand that affect firm’s investment. He aims to specify if potential variations in the financing cost contribute to the strengthening of a shock to the macroeconomy. Hall (2001) proves that the model which incorporates the financial accelerator mechanism, and

[32] Borrower's financial conditions are determined according to the portion of investment spending that can be financed by its own internal funds.

consequently accepts the potential operation of the balance sheet channel, describes better the recession of the early 1990s in the UK.

The financial accelerator effect is also used to describe the bank lending channel[33] in order to explain how a small monetary policy shift that causes changes in credit supply, can produce magnified and persistent effects on real aggregate economic activity.[34] In a recent study, Gertler and Kiyotaki (2010) provide evidence for the financial accelerator effect through a general equilibrium business cycle model, where information asymmetries restrict banks' access to new funds due to variations in their net worth. They incorporate financial intermediation in their model in order to examine its effect on real activity. Moreover, they do not take into account credit constraints by non-financial borrowers (e.g. firms), as discussed in the relevant literature, but examine only constraints that financial intermediaries confront during the crisis period. Banking institutions take the position of the borrowers as economic agents, while households are the lenders. Banks affect aggregate economic activity through the subsequent credit constraints that they face after an economic shock. Gertler and Kiyotaki (2010) assume the existence of constraints between financial intermediaries and their depositors (households), which limit the ability of the first to attract new funds and distribute them to non-financial borrowers due to the deterioration of their balance sheet conditions, especially, during contractionary periods where asset prices decrease. As a result, this situation amplifies the external finance premium, which implies an increase in the cost of credit for the borrowers. The financial accelerator effect is strengthened, while aggregate economic activity is weakened.

In addition, Cohen-Cole and Martinez-Garcia (2009), try to model the operation of the balance sheet channel in order to incorporate the new conditions (financial and credit market imperfections) that were formed during the recent financial crisis, -in which the banking system plays a crucial role- and reinforce the results of a shock over the cycle. They extend the Bernanke et al. (1999) model, by incorporating ”a regulated banking sector and frictions in the secondary market for used capital”, thus taking into consideration the role of the banking balance sheet. They examine the

[33] See among others Hubbard, Kuttner and Palia (2002) and Gambacorta and Mistrulli (2004).

[34] The operation of the financial accelerator mechanism is focused mainly on firms, as the only economic agents. However, it is also concerns households and banks, which determine their investment spending in relation to their net worth based on the magnitude of the cost differential.

effects of the banking regulations on the banks' lending channel, which change the operation of the transmission mechanism in the financial accelerator model of Bernanke et al. (1999).

3.2.1.1.2. Identifying the operation of the balance sheet channel through Investment Models

By using aggregate data it is difficult to specify if variations on borrower's level of investment are attributed to changes in credit supply or to changes in credit demand. More specifically, through the implementation of the financial accelerator effect, it is not possible to determine if the necessary positive relationship between aggregate credit and aggregate investment is implied by shifts in the supply of capital stock (changes in borrower's internal funds) or by shifts in the demand for capital stock, where the latter depend on borrower s' investment opportunities. Thus, the difficult part of the above process is to determine borrowers' investment opportunities. Various investment models are used in the empirical literature for this purpose. Another problem arises due to the difficulties in the estimation of the external finance premium. The accurate specification of firm's internal financing cost is not possible. Last but not least, by using aggregate data, potential endogeneity issues may arise (Bernanke et al., 1996). For these reasons alternative empirical methodological approaches are followed aiming to provide evidence that the balance sheet channel is operative.

Empirical research uses firm-level data, in order to capture the specific information asymmetries that borrowers face and specify the impact of these asymmetries on their investment policy. For this purpose, there are two different econometric approaches, which are followed in order to assess the operation of the balance sheet channel.[35] In the first, a number of different investment models are used aiming to specify the optimal level of investment demand, by estimating reduced-form investment equations, and by limiting, as much as possible, the number of the restrictive theoretical hypotheses. The reduced-form approach encompasses the neoclassical model, the accelerator model, and the Tobin's Q model. The second approach is the Euler equation model.

[35] Schiantarelli (1996).

The neoclassical model uses the user cost of capital and output, so as to estimate the investment equation for the determination of investment demand.[36] More specifically, the model aims to specify the optimal level of investment spending in order to maximize firm's utility. It examines the possible effects that changes in the cost of capital may exert on the capital stock to output ratio, while it does not take into account any price variables. The cost of capital is independent from the firm's specific characteristics and as a result the firm's optimization problem is not related to its financial structure. So, this approach does not take into account the probability the above examined relationship to be differentiated in firms with different financial conditions. The accelerator model assumes that changes in real output (Clark, 1917; Jorgenson, 1971) or sales (Abel and Blanchard, 1988) are the main factors for variations in the capital stock, which subsequently imply variations in real investment spending. The model does not take into consideration any price variables to explain changes in investment demand. However, correlation issues may arise due to the possible interdependence between firm's cash flow and sales.[37]

Two alternative models, based on the neoclassical model of investment, under the assumption that the real user cost-of-capital does not change, are Tobin's Q and the Euler equation. They are neoclassical formulations which arise from the dynamic optimization problem of a firm's value. Based on these models, researchers study the operation of the balance sheet channel, by examining cross-sectional changes in the borrower's balance sheet conditions, which specify the level of loan demand and as a result the level of investment spending. More specifically, they examine the significance of the borrower's financial constraints on its investment under conditions of perfect capital markets through reduced-form investment equations estimated on cross-sectional or panel data. This is achieved by incorporating different variables in the investment equations as proxies for the firms' balance sheet conditions (cash flow, coverage ratio, net worth, stock of liquid assets, total debt as a fraction of total assets,

[36] The initial form of the neoclassical model includes only the user cost-of-capital as the main factor that affects investment (e.g. Tinbergen (1941). Hall and Jorgenson (1967), and Jorgenson (1971) develop the neoclassical theory of investment that includes the level of output in the corresponding model.

[37] According to Fazzari et al. (1988) a weakness of the sales accelerator model is that "it does not incorporate the relative price of capital or capital services in the empirical specification".

etc.) and by testing their significance for borrower's investment.[38] Various criteria have been used in order to separate the sample based on the different information asymmetries that borrowers face. In case that these proxies are found to have positive and statistically significant effects on firms' investment, -especially after a monetary policy tightening which affects directly and indirectly borrower's balance sheet conditions-,[39] while they improve the explanatory power of the investment equation, this is a sign that the balance sheet channel is operational. By employing this approach there is no need to estimate the borrower's cost differential.

Tobin's Q model (Tobin, 1969) is used in the relevant empirical literature,[40] in order to specify optimal investment demand. In particular, the Q model aims to control for the existence of financial constraints for firms that are more likely to encounter information asymmetries, and, specify the effects of these constraints on their investment policy. It does not include the user cost of capital, but the value of the firm's assets. Investment to capital ratio is regressed on the ratio of the firm's total value to the replacement cost of its total capital stock (average Tobin's Q).[41,42] So, based on Tobin's Q theory, the market valuation of the firm's capital stock is the main factor which specifies investment demand.[43,44] Firm's investment spending will expand only in cases where the expected future profitability[45] of investment is greater

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[38] Many researchers use a number of different variables instead of investment, in order to capture the effects of variations in borrowers' balance sheet conditions (e.g. employment demand, R&D, inventory investment etc.).

[39] Bernanke and Gertler (1995).

[40] See Fazzari et al. (1988), Devereux and Schiantarelli (1990), Gertler and Hubbard (1988) among others.

[41] According to Hayashi (1982) average Q is used as a proxy for marginal Q under conditions of perfect capital markets. He argues that "if there are constant returns in the adjustment costs, then average Q equals marginal Q". Hayashi (1982) was the first who extended the Tobin's Q theory to investment models based on the assumption of convex costs of adjustment of the capital stock.

[42] Average $Q = (V_t + B_t – F_t) / (K_t + N_t)$, where V is the market value of shares, B is the market value of debt, F is the market value of financial assets, N is the market value of inventories, and K is the market value of the capital stock.

[43] A firm's investment spending will expand in case the marginal Q is higher than one and until it becomes equal to one. In this equilibrium point, marginal Q is equal to one and is also to average Q. Fazzari et al. (1988) define marginal Q as the shadow value of an additional unit of capital.

[44] Phillipon (2009) in a different approach based on Tobin's Q model, uses bond prices instead of equity prices (known as "Bond Q" model). Additionally, Gilchrist and Himmelberg (1995) use a vector autoregression model and develop the "Fundamental Q" model.

[45] According to Modigliani and Miller (1958) firm's investment opportunities represent firm's expected future profitability.

than the replacement cost of its total capital stock, under conditions of perfect capital markets.

Average Q is used to predict and capture firm's future investment opportunities and possible variations, which are crucial for the borrower's investment decision making. The firm's market value should reflect all the information about the firm's investment policy, when there are no imperfections in the capital markets. Researchers examine the cross-sectional changes in the firm's financial conditions, in order to verify the operation of the balance sheet channel. They incorporate a number of different variables (cash flow, liquid assets, short-term securities, etc.) in the Q model, which capture the firm's potential to expand its investment based on its own funds, in order to estimate the effects of financial constraints on the firm's investment. In case credit market imperfections exist, the average Q cannot be used to capture the firm's investment opportunities and specify the level of investment, and thus Tobin's theory does not exist. The latter will depend on the significance of the variables that are used as proxies for the firm's balance sheet conditions and they are incorporated in the Q model. So, if the variables examined are found to have significant effects on investment after the estimation of the Q model, this will be evidence for the presence of credit market imperfections and successively for the operation of the balance sheet channel. In this case, the estimated variables will also capture firm's investment opportunities due to the existence of imperfections especially for firms that present greater information asymmetries.[46]

An additional type of econometric model of investment behavior is the standard Euler equation model, which also describes firm's investment policy.[47] The Euler equation, instead of the Q model, is preferred, when there is no information about firms in the stock markets, or there is no sufficient data to construct the Q variable. The Euler equation is derived from the firm's value maximization problem. However, it uses measures of profitability that are independent from the market value of the firms. This allows to overcome the measurement error problems of the Q model

[46] The inclusion of the extra variables as proxies for borrower's internal finance in the Tobin's Q model should not improve the explanatory power of the model.

[47] See Gilchrist (1990); Hubbard and Kashyap (1992); Whited (1992); Hubbard et al. (1995) among others.

because there is no need to test and specify borrower's investment opportunities.[48] The Euler equation approach assumes that the firm’s current period's rate of investment should be dependent on next period’s rate. Similarly, as in the Q model, a variable is included as a proxy for borrower's financial conditions. In case that this variable has significant effects on investment demand, this signifies the existence of financing constraints and the misspecification of the Euler equation, because the assumption that there are no credit market imperfections will not be valid.[49,50] Thus, the balance sheet channel will be operative.

The main variable which is used widely in the empirical literature to examine if the relationship between investment and internal finance is considered as a reliable proxy for the existence of financial constraints, is cash flow.[51] Thus, the cash flow variable which captures borrower’s net worth[52] is used as a proxy for firms' balance sheet conditions and determines the source and the cost of firms' financing, as well as the extent of their investment, when there is imperfect substitution between internal and external finance in capital markets.[53] When the cash flow variable is significant, this is interpreted as evidence for the operation of the balance sheet channel. Therefore, the negative effects of a monetary policy shock are linked to the borrowers’ financial position, which determines their ability to find alternative sources of funding from credit markets, in order to counterbalance the reduction in cash flows and fulfill their investment plans.

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[48] According to Schiantarelli (1996), as in the Q model, an important issue connected with the Euler equation approach is that technology may be a significant factor for the rejection of the first order condition in the maximization problem. So, in the Euler equation, factors that cannot capture the existence of credit market imperfections are responsible for measurement problems. More details about the possible drawbacks of the Euler equation approach are presented by Schiantarelli (1995).

[49] Agung (2000).

[50] The Euler equation will be misspecified for a firm that does not pay any dividends (Gilchrist, 1990), or is at its maximum level of debt which is feasible (Hubbard and Kashyap, 1992), if the hypothesis of perfect capital markets is not true.

[51] The main arguments for the use of the cash flow variable are the high availability of the data and the fact that it captures the firm's market value. Boivin et al. (2010) calculate cash flow as the difference between cash receipts and cash expenditure.

[52] Schiantarelli (1995) defines net worth as the firm's liquid assets plus collaterizable illiquid assets. He argues that the calculation of net worth has difficulties because it depends on borrower's future returns. For this reason cash flow is used extensively in empirical studies.

[53] As Walsh (2003) notes "with agency costs creating a wedge between internal and external finance, measures of cash flow, net worth, and the value of collateral should affect investment spending in ways not captured by traditional interest-rate channels".

However, there are many researchers (Gilchrist and Himmelberg, 1995; Hubbard 1998, among others) that dispute the use of the cash flow variable as a proxy for firm's internal funds.[54] They argue that the inclusion of the cash flow variable in an investment equation may be problematic, due to the fact that it can include information about firm's investment future profitability in addition to the level of borrower's financial constraints. On this occasion, correlation issues may arise between cash flow and firm's future investment opportunities, which implies misleading results about its significance, and in this way about the existence of credit market imperfections. The Q model allows to deal with the above issue by capturing changes in firm's future investment opportunities (Fazzari et al., 1988; Devereux and Schiantarelli, 1990). In case that the Q variable is found to be significant, then the cash flow variable that is also included in the model, will provide evidence in a reliable way about the existence of financial constraints for the firms. This is the main reason for the extensive use of the Q model in the empirical literature.[55] Furthermore, researchers argue that the inclusion of the cash flow variable in a regression equation can also provide ambiguous results, due to the different probability of the existence of financial constraints for the firms. For this reason, the regression equation is estimated for groups of firms that are classified according to specific characteristics (specified in an ad hoc way), which capture borrower's potential financial constraints. In this case, the significance of the cash flow variable provides reliable evidence for the existence of financial constraints for borrowers due to the credit market imperfections.[56]

There are many studies[57] that classify firms according to the magnitude of the credit market imperfections and so according to the level of external financial constraints

[54] Cummins et al. (2006) claim that "studies that employed Q models may have found significant cash-flow effects either because fundamentals were poorly measured or because lags of Tobin's Q were used as instruments".

[55] However, Gomes (2001) disputes the use of the average Q due to the significant collinearity with the cash flow variable. He proves that the cash flow variable does not contribute to extra explanatory power in the Tobin's Q investment model.

[56] It should be noted that the existence of a relationship between investment and cash flow variables can be misleading, due to the fact that managers have personal incentives to raise firms' investment spending (power, higher wages etc.) and do not aim to maximize their value. Managers resort to the firm's internal finance so as to be more unrestrained to achieve their purposes, without external surveillance from the outside lenders. So, the significance of the cash flow variable will not actually prove the existence of financial constraints.

[57] Agca and Mozumdar (2007) argue that factors which lessen capital market imperfections contribute to the decrease of the investment-cash flow sensitivity.

that exist in raising external funds, and thus affect the firms' investment policy. Different variables are used as proxies for this purpose. The main ones are size and age (Devereux and Schiantarelli, 1990), the dividend payout ratio (Fazzari et al., 1988), the presence of bond rating (Whited, 1992), credit rating (Chatelain et al., 2003), and the degree of shareholders concentration (Agca and Mozumdar, 2007). The above variables show how vulnerable the firms' investment spending is, in regard to the impact of information asymmetries, which restrict their access to external finance. The results of these studies are in the same line with those of Fazzari, Hubbard and Petersen (hereafter FHP) (1988).

FHP (1988), in a benchmark work in this field of research, are the first who study the relationship between investment and cash flow, in order to specify possible financing constraints for a firm. They classify firms based on the level of financing constraints they face, according to their level of dividend payout ratios, aiming to specify divergences in the level of investment which is affected by their net worth (cash flow). FHP incorporate Tobin’s Q and cash flow variables in the regression of investment under examination, in order to capture firm’s investment opportunities.[58] They prove that there is a significant monotonic relationship between investment and cash flow. They conclude that because of imperfect substitution between internal and external finance, a firm with low dividend payments, faced with a reduction of its internal funds, would have to reduce its investment more, than a firm, which pays out high dividends. Thus, the more intense the credit market imperfections are, or the greater the level of financial constraints that a firm faces is, the more sensitive the relationship between investment and cash flow is. Their results are in the same line with the financial accelerator mechanism. However, their approach is not based on a structural approach.

On the other side, a large part of the empirical literature classifies firms according to the level of their internal financial constraints, which are relevant to the availability of internal funds as a source of investment financing. Variables that have been used to specify the intensity of these constraints are, inter alia, liquidity (Cleary et al., 2007), the cash flow ratio, the debt ratio, and the current ratio (Cleary, 1999), sales growth,

[58] FHP (1988) consider Tobin’s Q as a cash flow measure, which works complementary to the cash flow variable.

and the coverage ratio (Guariglia, 2008). These studies extend the results of Kaplan and Zingale's (1997) research.

Kaplan and Zingales (1997) use the same sample as FHP and the same methodological approach, however, they classily firms based on different criteria. They consider that the categorization of firms according to their dividend policy is not rational.[59] More specifically, they use data from annual reports of the firms and the management's discussion of liquidity. They separate the firms into five different groups, according to the likelihood of being financially constrained. On the contrary to FHP (1988), they show that the investment-cash flow sensitivity of "less financially constrained" firms is higher.[60] They argue that the cash flow variable can possibly be used as a proxy for profit expectations. Thus, the inclusion of the cash flow variable in an investment equation is not a reliable process to specify the potential effects or credit market imperfections on investment and could possibly lead to incorrect conclusions about the level of financial constraints. FHP (2000) argue that Kaplan and Zingale's (1997) work is not reliable due to the classification scheme which is followed in order to separate firms with different level of financial constraints. The main objection of FHP (2000) is that Kaplan and Zingale's approach considers firms which are financially distressed as financially constrained, so this implies classification issues.

In the same direction, many empirical studies in recent years use panel data in a neoclassical model of investment, so as to examine the existence of the balance sheet channel. Chatelain et al. (2001), use micro firm-level data to estimate investment equations, in which they examine the significance of the weighted average user cost of capital,[61] sales and cash flow. This allows them to specify the different channels of monetary policy and quantify the elasticity of the investment to monetary policy. They develop an autoregressive distributed lag model for their purposes. They take into consideration possible financial frictions and separate the sample based on the

[59] Moreover, the methodological procedure followed by FHP (1988) is criticized because of the possible measurement errors of the average Q.

[60] In the same direction, Cleary (1999) argues that the investment-cash flow sensitivity is higher for unconstrained firms.

[61] In an alternative approach, Von Kalckreuth (2003) uses the theoretical user cost of capital, as he argues that it captures the pure price effects in a better way, while it is independent from firm-specific financial constraints.

firms' size. The significance of the variable which is a weighted average of the cash flow and the cost of capital verifies the operation of the balance sheet channel.

There are a few studies that investigate the investment-cash flow sensitivity when there is a monetary tightening. Oliner and Rudebusch (1996) argue that monetary policy actions specify the external finance premium due to the effects of these actions on borrowers' balance sheets. For example, a monetary easing improves the balance sheet conditions (net worth) of firms through increases in the value of collateral that they can use in order to attract new external funds. This situation has positive effects on their external finance premium and subsequently on real investment and output. Based on a neoclassical investment model, the authors examine the operation of the broad credit channel (they use an alternative definition of the balance sheet channel). Specifically they investigate the relationship between investment and internal funds for the US manufacturing sector after significant changes in monetary policy from the 1960s to the 1990s. They classify their sample based on the size of firms, because they hold the view that information asymmetries should be greater for smaller firms. In case that the broad credit channel is operative, then the examined relationship should be stronger, when a negative monetary policy shock occurs. This relationship signals a higher external finance premium.[62] On the contrary when the channel is inoperative the aforementioned connection should present significant changes over time. They show that a monetary tightening verifies the operation of the channel for small firms, which are obliged to limit their investments. They also observe that the relation between investment and internal finance is not significant after a monetary easing by the authorities.

3.2.1.1.3. Identifying the operation of the balance sheet channel through alternative empirical approaches

There is a number of issues concerning robustness on the inclusion of a proxy variable for borrower's internal finance into an investment equation. Beyond the problems that are connected with the use of the Tobin's Q investment model,[63] it is

[62] Oliner and Rudebusch (1996) specify the cost of firm's internal finance as the sum of the risk-free interest rate and the risk-adjusted interest rate appropriate for each firm, while the cost of external finance is calculated as the sum of the cost of internal funds and a cost which depends on the level of the firm's borrowing and the risk-free rate.

[63] There are some concerns about the use of the Tobin's Q model. According to Schiantarelli (1995) the use of the Q model, entails the risk that the "average Q may be a very imprecise proxy for the shadow

also possible to find significant investment-cash flow sensitivity without the existence of financial constraints. Moreover, a disadvantage of this approach is that it does not assume the procyclicality of a firm's net worth, as it is necessary, in the financial accelerator mechanism. According to Ćorić (2010) cross-sectional and panel data studies do not specify the magnitude of the procyclicality of firm's net worth and the aggregate effects of these results. Hovakimian and Titman (2006) and Almeida and Campello (2007) give a partial solution to the abovementioned problems.

Also, the selection of the criteria that capture single or multiple indicators of a firm's financial conditions is an important issue. Schiantarelli (1995) underlines that endogeneity issues may arise as far as the different variables that are employed for firms' classification are concerned. Moreover, Schiantarelli (1995) claims that an important issue concerning the classification of the firms according to one firm specific characteristic, is that this "single indicator may or may not be a sufficient statistic for the existence of liquidity constraints". Furthermore, problems may emerge due to the use of more than one criterion in order to separate the sample -the number of the parameters under estimation will be high-, which implies difficulties during the estimation of the model. Last but not least, researchers express disagreements in regard to the static way of the firm's classification, as it is considered possible for the level of the financial constraints to change during time. Thus, it is difficult to determine if time-invariant or time-varying criteria are more appropriate for the borrowers' classification, as constrained or unconstrained. In order to deal with these issues alternative approaches are used.

The endogenous switching regression approach solves the last problem. It does not classify firms according to specific criteria. The firm status, as constrained or unconstrained is specified according to specific data based on a switching function. Therefore, the sample separation is dynamic, because the criteria used for the firm's classification, in order to determine the magnitude of each firm's financial constraints, are specified endogenously. Quader and Taylor (2014) estimate endogenous switching regression models,[64] in which they include a corporate efficiency index as a measure of information asymmetries based on a stochastic frontier analysis. This aims to

value of an additional unit of capital". Gilchrist and Himmelberg (1995) find that measurement error problems connected with Q have consequences on the relation between investment and internal funds.

[64] Almeida and Campello (2007), Hu and Schiantarelli (1998), among others, use switching regression methods that allow changes in firms' classification.

specify potential effects of cash flow on corporate investment under conditions of imperfect capital markets and costs. In this way, they are able to specify the firm's efficiency which moves inversely to the level of agency costs. This approach allows firms to be classified endogenously based on the level of their financial constraints. They find that the differences between external and internal cost of finance, due to the presence of credit market imperfections, reinforce the sensitivity between investment and cash flow. Thus, they include efficiency in the investment equation in order to examine investment-cash flow sensitivity. This sensitivity is higher for firms which are more financially constrained, whereas it is lower when firms become more efficient and as a result less financially constrained.[65] Conclusively, they observe a non-monotonic effect of corporate efficiency on firm's investment-cash flow sensitivity.

Cleary et al. (2007) interpret the results of the studies, which show that there is a positive monotonic relationship between investment and internal funds, as a consequence of the "restrictive assumptions about firm's investment or financing opportunities, or ad hoc assumptions about the costs of external finance". They construct a model in order to show that the level of internal funds influences firm's investment. They find a U-shaped relationship, when the sample is classified, according to the availability of the firm's internal funds. Specifically, they show that when a firm's internal funds are high, investment increases monotonically with internal funds. On the contrary, concerning low levels of internal funds, where a financial wedge of the firm is observed, they find a negative relationship between them. Thus, the investment-cash flow sensitivity is lower for firms which face higher financial constraints. In the case where the firms are classified on the basis of the credit market imperfections, the investment-cash flow sensitivity is higher for firms which face higher financial constraints.

Based on a different methodological approach, Guariglia (2008) asserts that the deviations in the results of FHP (1988) and Kaplan and Zingales (1997) studies arise due to the various classification criteria. Guariglia (2008) uses the cash flow[66] and the

[65] Quader and Taylor (2018) argue that investment-cash flow sensitivity could also arise due to measurement errors in investment opportunities.

[66] Guariglia (2008) uses cash flow as a proxy for internal funds because it can take both positive and negative values. She argues that there are some concerns for the use of cash flow, as it is a flow variable, so it cannot include the stock of capital which was formed in the past.

coverage ratio, as proxies for the internal financial constraints, and the firms' size and age for the external ones, in order to study the investment-cash flow sensitivity of a panel of unquoted UK firms. She estimates an error correction model, which allows to overcome the criticism that the cash flow may be an important determinant of investment. This is simply because it accounts for investment opportunities, which are poorly measured by Tobin's Q. According to Guariglia (2008) the advantage of an error correction model in relation to the Q model is that it "maintains the long-run properties of value-maximizing investment models, but does not impose the restrictions on short-run dynamics associated with particular adjustment cost specifications". Therefore, based on a VAR model she can specify the present value of the firm's profits, which is used in an investment equation in addition to a proxy variable for firm's internal funds. The results provide evidence of a U-shaped relationship between investment and cash flow when the sample is separated by the level of internal funds. However, this relationship monotonically increases, when the level of the firm's external financial constraints is used. Guariglia concludes that the relationship between investment and cash flow is stronger for those firms which face higher external financial constraints and lower internal ones.

Ashcraft and Campello (2007) develop an empirical approach in a diversified framework, in order to verify the operation of the balance sheet channel and its contribution to the transmission of monetary policy. They employ a structural VAR model to distinguish the demand and supply-side effects. They use a two-step empirical methodology. In the first step they run cross-section regressions so as to specify the balance sheet sensitivities, while in the second they use the coefficients from the first step and run time series regressions. The different responses of the firms' investment to a monetary policy action are attributed to the existence of financing constraints. The authors prove that the balance sheet channel is active and works independently from the operation of the bank lending channel, especially, during periods of recession when a firm's balance sheet conditions are weaker. They use a sample of small subsidiary banks, which were affiliated with the same bank holding company with activities in different geographical areas. They conclude that through the operation of the balance sheet channel, a monetary change is magnified and propagated with stronger effects on aggregate economic activity. The authors stress that the weaker borrowers' net worth is, the higher the potency of the channel and its effects on investment will be.

Ascioglu et al. (2008) classify firms as more or less financially constrained according to market-based measures of asymmetric information. They use effective spreads, the price impact of trade, and the probability of informed trade (PIN) in order to measure the degree of financial constraints more directly. They conclude that the higher the information asymmetry for a firm is, the more sensitive its investment spending to cash flow is. Despite this, they find that there is a non monotonic relationship for firms with low probability of informed trade.

Angelopoulou and Gibson (2009) study the investment-cash flow relationship in order to specify the operation of the balance sheet channel by using a panel sample of UK manufacturing firms during periods of significant monetary tightening and between periods of financial development. They argue that procyclical changes in a firm’s net worth cause procyclical movements in the firm’s investment, as well. This leads to accelerator effects that reinforce the magnitude of economic cycles. They examine the connection between the financial constraints of a firm and changes in monetary policy. For this purpose, the authors form a monetary tightness indicator based on the narrative approach of Romer and Romer (1989). They classify the sample of firms according to their size and financial policy and prove that firms with greater financial constraints have greater investment-cash flow sensitivity, while this sensitivity is higher when there is a monetary policy tightening. Conclusively, they provide evidence for the existence of the balance sheet channel, which operates complementary to the other channels and contributes to the reinforcement of initial monetary shocks through variations in borrowers’ net worth.

We observe that several models have been used in order to examine the significance of the financial constraints on the level of investment. Their purpose was to examine if investment spending of firms, which face greater informational asymmetries, responds differently to a shock that affects their net worth. Nevertheless, we observe that there is no specific pattern that describes the relationship between investment and cash flow. Hence, it is not clearly defined whether the relationship between investment and cash flow could be used as reliable proof for the existence of financial constraints. This relationship is determined on the basis of the methodology applied and the different variables, which are used for the firms’ classification, in order to measure the financial constraints. However, the strength of these constraints may affect a sample of firms in a different way, depending on the variations of monetary policy, the fluctuations during the business cycle, the changes in financial markets, and the specific conditions that exist for each firm separately. Furthermore, the investment-cash flow sensitivity varies depending on the wedge between external and internal finance. Consequently, we argue that it does not matter which variables are used in order to split the sample, because there are no adequately specified reasons according to which the classification of firms affects the relationship between investment and cash flow.

3.2.2. Overview of the bank lending channel

The monetary policy transmission mechanism can have significant effects on the real economy not only via the balance sheet channel, but, also via the operation of the bank lending channel, and particularly through variations in bank loan supply. The bank lending channel is connected with the banks' operation, and reinforces the function of the interest rate channel. Bank balance sheet conditions determine the level of financial frictions and as a result the operation of the bank lending channel. The banking system contributes to the guarantee of the normal function of credit markets and ensures financial stability. In particular, banking institutions help in overcoming information asymmetries in credit markets between borrowers and lenders. Also, through credit provision, complementary to money and bonds, spending and investment are reinforced, with subsequent positive effects on the growth of real economic activity. Thus, their role is crucial, especially, during periods of monetary contraction.

A reduction in the supply of bank loans to borrowers, after a monetary shift, implies a further reduction in their investment expenditures. Banks retain deposits depending on their reserves and the supply of loans. Hence, when a contractionary monetary policy leads to a decrease in bank reserves, and consequently, in bank deposits, this leads to a lower supply of new loans. This is the basic line for the verification of the operation of the bank lending channel.[67]

[67] In the empirical literature we find an alternative lending channel beyond the conventional bank lending channel (see e.g. Van de Heuvel, 2002; Boivin et al., 2010). It is known as the bank capital channel. Banks, based on the level of their capitalization, adapt their balance sheet after a monetary

A disturbance in the provision of bank credit could possibly lead to the rise of the cost differential for those borrowers whose activities are strongly dependent on bank credit. This happens specifically to small firms whose access to credit markets is not always assured and are not able to absorb reductions in bank loan supply. These borrowers are obliged to seek new sources of financing, so as to fund their investments. Therefore, it is possible to find difficulties in substituting these funds with alternative sources of finance, without extra costs. If this is not feasible, the borrowers' ability to fund new investments is reduced, and thus, total output also decreases. We see that the contribution of the banking system to the reduction of credit market imperfections for ensuring financial stability is valuable. Bank credit is considered as one of the most privileged sources of funding for businesses, as banks have the ability to mitigate credit market imperfections.

The necessary condition for the operation of the bank lending channel is the imperfect substitutability between bank credit and other sources of external financing for firms as well as between loans and securities for banks.[68,69] So, a monetary contraction will entail a reduction in banks' credit supply. This happens due to imperfect substitution between credit and bonds on the asset side and between bonds and deposits on the liability side. Thus, firms that are strongly dependent on bank loans will have to limit their investments. If the above hypothesis is not true, then the Modigliani and Miller's financial irrelevance theorem should apply. In this case, loan demand and demand for bonds cannot be separated.

The only structural model, and the benchmark model as regards to the interpretation of the bank lending channel, is the Bernanke and Blinder (1988) model. The authors suggest that the credit channel complements the function of the interest rate channel. In the model which they develop, they include the loan market in the conventional IS-

change. The lower the amount of capital they hold, the weaker loan growth will be. Thus, monetary policy shifts that have significant effects on bank equity capital also lead to changes in bank lending.

[68] Bernanke (1993) argues that a prerequisite for a bank loan to act independently in the transmission of monetary policy, and thus, the bank lending channel to incur, is the imperfect substitution between loans and bonds for firms, and between loans and securities for banks because of the imperfections in financial markets.

[69] De Bondt (1999) highlights that two conditions have to be satisfied in order for the bank lending channel to be effective. The first condition is that there is no perfect substitute for bank loans, both, for borrowers and lenders, while the second condition is that the monetary policy can reduce bank lending via the adjustment of bank reserves.

LM model aiming to study the bank lending channel.[70] A contractionary monetary policy reduces bank deposits, which in turn implies a reduction in aggregate loan supply. They conclude that, because of the imperfect substitutability between bank loans and bonds for banks and/or borrowers, there is an additional channel that strengthens the influence of monetary policy on aggregate demand.

It is important to determine the different effects that movements in loan demand and loan supply exert on the quantity of bank loans.[71] By doing this, we can find evidence for the operation of the bank lending channel. In any case, the different effects exerted on aggregate demand, from variations in loan supply and loan demand, are not fully clarified in the literature. There are different methodological approaches to solve the identification problem. Specifically, Brissimis and Magginas (2005) use aggregate time-series data in order to test the potency of the bank lending channel, by examining, whether changes in financial markets affect asset substitutability. This is the only study that directly assesses the Bernanke and Blinder model. They use multivariate cointegration techniques in order to test a number of restrictions that are necessary for the existence of perfect asset substitutability. They observe that, as the modern financial system tends, more and more, to a market-based structure, the role of the bank lending channel, regarding the transmission of monetary policy, is weakened. They conclude that the bank lending channel is inoperative in the U.S. during the '80s and '90s.

Furthermore, Brissimis and Delis (2009) use panel data, assuming that there is perfect competition in the banking system and that the loan interest rate is constant across banks for a given time period. This approach allows the direct assessment of the loan supply function. They establish the existence of the transmission channel of monetary policy through banks, but, only in countries, whose banking system is not very much liberalized, and, constitutes their main source of funding. The operation of the bank lending channel is strongly rejected in the U.S. for the period from 1994 to 2007.

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[70] Bernanke and Blinder (1988) show that the bank lending channel is not active when the elasticity of loan supply, in relation to the interest rates, tends to infinity, or when the loan demand is perfectly elastic, with respect to the interest rates, and the demand for output is not affected by changes in the interest rate spread.

[71] We are able to identify shifts in loan supply, and shifts in loan demand, as bank loans and bonds are not perfect substitutes.

A significant number of studies pursued to test for the operation of the bank lending channel by examining timing relationships between quantity or price variables and monetary policy variables.[72] Kashyap, Stein and Wilcox (1993), use the issuance of commercial paper, as a proxy for loan demand, in order to distinguish loan demand from loan supply effects and verify the operation of the bank lending channel. They examine the ratio of bank debt to commercial paper debt by employing aggregate data. They conclude that a tightening of monetary policy increases commercial paper issuance, while the supply of bank loans decreases, which indicates the operation of the bank lending channel. Only if the interest rate channel functions, the proportion between bank loans and commercial paper would remain constant.[73]

According to Brissimis and Magginas (2005), these studies capture only the short-run relationships between the series and thus are not able to provide reliable results concerning shifts in loan supply which is a necessary condition for the existence of the bank lending channel. Due to loan commitments banks do not react immediately after a monetary shock. So short-run responses could not be informative and verify the operation of the bank lending channel, through shifts in loan supply.

In confronting this issue, many studies use disaggregated cross-sectional data in order to face the identification problem and confirm the operation of the bank lending channel. The basic approach is the estimation of reduced-form bank loan equations, by using bank-level data, in which different specific bank characteristics such as size, age and liquidity, capitalization, etc., are analyzed. This is followed in order to capture banks' loan supply responses to a monetary impulse. If these characteristics are significant, this is an indication of the existence of the bank lending channel.[74] In the following we present some interesting results of a number of different studies.

[72] After the inception of the crisis, studies concerning the effects of monetary transmission channels on aggregate economic activity are few. The majority of the researches examine the effects of monetary shifts on specific financial indicators, such as interest rates (see e.g. Krishnamurthy and Vissing-Jorgensen, 2011).

[73] In a similar approach, Black and Rosen (2007), by using loan level data, they contend that it is not necessary that differences in bank loan supply between large and small firms should exist for the operation of the bank lending channel, while they accept that banks restrict their loan supply at an aggregate level after a monetary tightening.

[74] We have to note at this point that the main hypothesis of this approach is that bank characteristics do not affect loan demand, but loan supply only.

Kashyap and Stein (2000) find that American smaller-sized banks, and those who hold less liquid assets, are forced to restrict lending during periods of monetary tightening, as raising external financing becomes more difficult. Nevertheless, they conclude that the operation of the bank lending channel refers to that part of the banking system that is responsible only for a small share of total bank lending in the U.S.. Kishan and Opiela (2000) find in their study that American banks with higher capitalization, and therefore less leverage, respond more effectively in safeguarding their ability to supply loans in case monetary policy makes financing harder.

Campello (2002) shows that small-sized banks can respond to a change in monetary policy, without reducing their debt, as long as they are part of a large banking network that can provide them with additional funding through internal capital markets. Cetorelli and Goldberg (2012) show that the lending channel works for large-sized American banks which are restricted to domestic operations without international perspectives. Unlike, the large banks that have expanded their activities worldwide and have the ability to absorb monetary policy changes rely on domestic capital markets and their foreign subsidiaries. Finally, they note that the bank lending channel in the U.S. becomes weaker to an even greater extent, as the banking system is globalized. Ashcraft (2006) shows that the existence of internal capital markets in bank holding companies limits the negative effects of a reduction in the available bank credit caused by a monetary contraction. This in turn limits the operation of the bank lending channel.

Gambacorta and Marques-Ibanez (2011), by utilizing bank level data for the period from 07/2007 to 12/2009, find that changes in banking models and market sources of funding (e.g. securitization) differentiate the mechanism of transmission of monetary policy in both Europe and the U.S., while they also provide evidence that the bank lending channel was strengthened. In particular, banks with a weaker capital base, a greater reliance on market financing and non-interest bearing income sources, reduced the supply of loans to a greater extent during the period under review. Thus, Gambacorta and Marques-Ibanez (2011) assert that non-financial corporations that have access to corporate bond market and derive significant amounts of funding, can overcome the bank credit constraints.[75]

[75] This fact questions the main assumption of Bernanke and Blinder (1988) model for imperfect substitutability between loans and bonds, especially for large borrowers, as a necessary condition for

The empirical literature yields mixed results concerning the operation of the bank lending channel in the Euro area. Favero et al. (1999) show that the bank lending channel did not work in France, Spain, Germany and Italy in 1992, when monetary conditions were tightened. In their study, Ehrmann et al. (2003) try to discriminate the effect of loan supply from the corresponding effect of loan demand on aggregate lending, following a monetary policy change, by using reduced-form equations. They assume that the response of loan demand is homogeneous among different banks. Their main aim is to observe cross-sectional differences between banking institutions, by examining specific characteristics, which influence their ability to offset a contingent reduction of available deposits, after a monetary policy shock. They derive the basic principles underlying the application of the reduced-form equation, from a structural banking model, under the condition of imperfect competition. Ehrmann et al. (2003) prove that liquidity is an important factor that affects loan supply functions of banks in most European countries. Altunbas et al. (2002) show that banks' ability to provide new loans is affected to a greater extent after a sudden change in monetary policy when their capitalization is lower.

According to De Bondt (1999), a decline in bank securities, relative to credit in the short run is a sign of functioning of the bank lending channel. The factors that limit the operation of the lending channel are monetary policy conducted by individual monetary authorities, and, the scope of banking activities. Specifically, monetary authorities determine the minimum reserve base and the possibility of banks to use funding sources -apart from deposits- in order to finance new loans. Also, banks with international orientation have better access to foreign funds, than global credit markets or affiliated banks. Haas and Van Lelyveld (2003) argue that in most cases, foreign banks, that are part of a large international banking organization, cope better with potential tightening of monetary policy in times of crisis since they enjoy the support of their parent organizations.

Altunbas et al. (2007) find that the channel in the European area operates through bank credit risk. In particular, they find that specific bank characteristics (size, liquidity, capitalization, etc.), in conjunction with the bank risk conditions, should be taken into account jointly, in order to assess the ability and the willingness of banks to

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the operation of the bank lending channel and it constitutes a strong sign for the non-existence of the bank lending channel.

provide new loans. They conclude that banks with lower expected default frequency and thus lower credit risk levels respond better to changes in monetary policy by maintaining or increasing the credit supply. In another study of the European banking system, Altunbas et al. (2009) examine the impact of securitization on the effectiveness of the bank lending channel and the ability of banks to grant new loans. They conclude that the use of securitization deters any potential reductions in the provision of new bank loans after changes in monetary policy. However, during the crisis, where financial pressure is more pronounced, the role of securitization may be reversed.

Moreover, Havro and Vale (2011) in their study provide evidence for the operation of the lending channel in the Norwegian banking system. Bank credit supply is limited by an increase in the interest rate, while those banks with higher capitalization and more liquid portfolios respond better to the interest rate changes. Alper et al. (2012), utilizing data from Turkish banking institutions, find that monetary policy has brought about changes in both the liquidity of individual banks and the systemic liquidity in the banking system, thus, affecting the supply of new credit from the banking sector. In a different approach, Brissimis et al. (2014) use bank market power, in order to test the operation of the bank lending and risk-taking channels over the period 1997 to 2010 for US and Euro area banks. They show that in the period that follows the global financial crisis, under the new conditions that prevailed, the potency of the bank lending channel was strengthened. This was because higher levels of market power were required, in order to shield bank loans and credit risk from monetary variations.

However, according to Brissimis, Kamperoglou and Simigiannis (2001), the reduced-form equation approach does not allow the identification of the basic parameters of the Bernanke-Blinder (1988) structural model, which are necessary for the operation of the bank lending channel, whereas there could be measurement biases because the explanatory variables have only a time dimension. Furthermore, it is not possible to derive potential equilibrium relationships, because variables are in first-differences. For the above reasons, they use an alternative more structural approach[76] and directly estimate the loan supply function, by using panel data.

[76] The same methodological framework is followed by Farinha and Robalo Marques (2003), who examine the operation of the bank lending channel for Portuguese banks.

As mentioned above, the distinction between shifts in loan demand and shifts in loan supply is a subject that has been extensively analyzed in the literature. Consequently, in order to determine whether the bank lending channel operates or not, we should consider whether the monetary policy has the power to influence the supply of bank loans. Thus, it is crucial to emphasize that for the operation of the bank lending channel, the necessary condition is the imperfect substitution between bonds and loans, not only for banks, but, also for borrowers. In this case, a monetary tightening that restricts bank deposits and as a result bank loan supply has significant effects on aggregate demand, beyond the effects of the conventional interest rate channel.

3.3. The theoretical framework

3.3.1. The model

This section develops the theoretical framework, which is based on the Bernanke and Blinder (1988) model, extended to incorporate imperfect substitution between internal and external finance of firms, and thus allowing to put to a structural test both the bank lending and balance sheet channels of monetary policy transmission.

Two essential features of the proposed framework are distinguished. Firstly, because of the existence of informational imperfections, different types of finance for firms are imperfect substitutes. The bank lending channel assumes imperfect substitution between loans and bonds, both of which are types of external finance. The balance sheet channel, on the other hand, assumes imperfect substitution between internal and external finance. With a changing financial structure, firms are facing a cost differential when raising finance from different sources. Secondly, the cost of capital influencing investment decisions is a weighted average of the cost of individual types of finance and this in turn implies the interdependence between changes in financial structure and investment demand (and thus output demand).

Our model is assumed to be linear for analytical convenience and contains the basic components of the financial structure by specifying demand equations for these components and also a supply equation for bank loans, which is an item of the firms' external finance. Table 3.1 and Figure 3.1 below presenting the structure of total liabilities in the firms' balance sheets and the cost of the main components, help us in making a number of simplifying assumptions that allow to obtain analytical results: (i) The "other liabilities" item of external finance (see Table 3.1), including inter alia trade accounts and all other liabilities, both current (e.g. excise and sales taxes) and non-current (e.g. deferred income taxes), are excluded; these represent about one third of total liabilities and are not likely to be influenced by (real) rates of return. (ii) Equity finance is also not considered as firms tend to maintain an inflexible level of dividends per share,[77] an empirical regularity pointed out in the seminal work by Lintner (1956), which still has continuing validity.

Table 3.1: Sources of finance (end-year figures, percent of total)

Type of finance	1994	1995	2000	2005	2010	2015	2017[a]
Internal finance							
Retained Earnings (R)	22.1	22.7	23.3	24.8	28.3	29.6	28.0
External finance							
Loans (L)	9.3	9.5	9.8	6.6	6.3	6.7	6.8
Bonds (B)	16.4	16.0	15.0	14.1	17.0	21.1	21.7
Equity (E)	13.9	13.9	15.5	17.5	16.0	10.5	11.9
Other Liabilities (O)	38.3	37.9	36.3	37.0	32.5	32.1	31.5
Total (bn USD)	4036	4381	6058	7744	10068	13128	14199

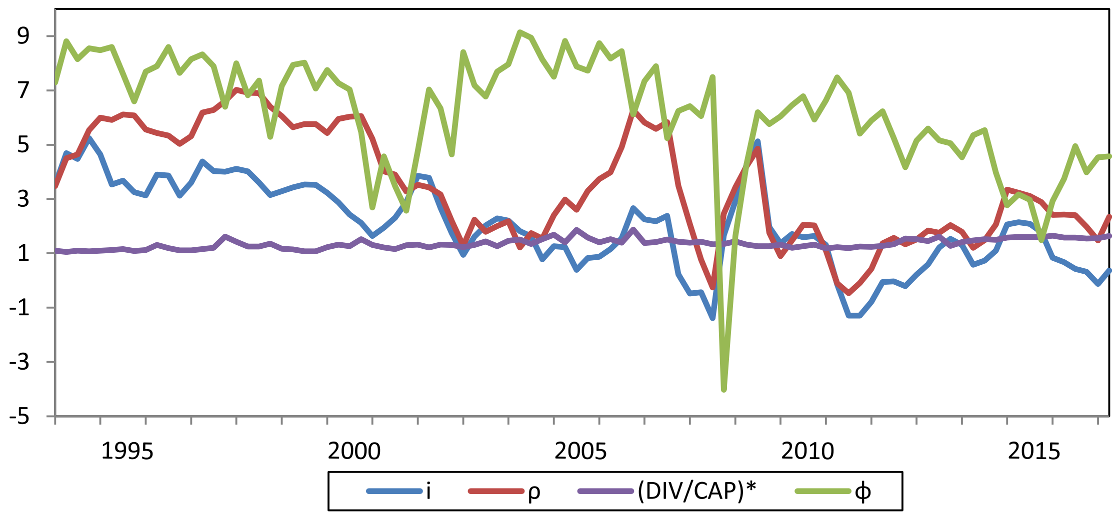
Notes: R: retained earnings (stock); L: bank loans; B: bonds; E: stockholders' equity; O: other liabilities.

[a] The figures refer to 2017:Q2.

Source: QFR database and author's calculations.

[77] This corresponds to the (real) cost of equity capital at the aggregate/macro level.

Figure 3.1: Real cost of corporate finance (in percent)



Notes: i: bond rate (10-year Government Benchmark bond yield); ρ: bank lending rate (bank prime loan rate); φ: cost of retained earnings; DIV: dividends; CAP: capitalization.

* The cost of equity is defined as the ratio of total dividends to total capitalization.

Source: FRED and QFR databases and author's calculations.

Figure 3.1, presenting the real cost of the different forms of corporate finance, shows that the cost of equity has historically, at least in our sample, been "sticky" (remained essentially constant), in contrast to the cost of other types of finance which fluctuated considerably.

In our model the role of bonds, as in Bernanke and Blinder (1988), is not considered by appealing to Walras's law. Also, as in the above study, we assume that the expected inflation rate is constant, so we suppress it because a Keynesian-type model takes both the price level and inflation as given.

The loan market in the model is specified as follows:

$$L^d = a_0 + a_1 y - a_2(\rho - i) - a_3(\rho - \varphi) \qquad a_1, a_2, a_3 > 0 \qquad \textbf{(3.1)}$$

$$L^s = b_0 + b_1 D + b_2(\rho - i) \qquad b_1, b_2 > 0 \qquad \textbf{(3.2)}$$

$$L^d = L^s = L \qquad \textbf{(3.3)}$$

where L, y and D are real loans, output and deposits, (ρ-i) is the spread between the bank lending rate (ρ) and the bond rate (i), (ρ-φ) is the spread between the bank lending rate (ρ) and the rate of return on retained earnings (φ),[78] while superscripts d and s refer to loan demand and loan supply, respectively.[79] Loan demand is negatively related to both interest rate spreads and positively to the output variable. The latter is the scale variable in Eq. (3.1), while the deposit variable has the same role in Eq. (3.2). Variations in the interest rate spread (ρ-i) and deposits affect loan supply positively. The inclusion of the spreads in Eqs. (3.1) and (3.2) is based on the premise that borrowers' financing decisions and bank portfolio decisions are characterized by rate of return homogeneity. In this case, an equal increase in the financing costs for all forms of borrowing, will not affect the structure of the firms' liabilities, while banks' loan supply policy depends on the relative return on loans. Moreover, the inclusion of the interest rate spread in both equations implies that loans and bonds are imperfect substitutes in bank portfolios or as sources of external finance for borrowers. Eq. (3.3) is the equilibrium condition for the loan market.

The demand for retained earnings equation is specified as:[80]

$$R = c_0 + c_1 y - c_2(\rho - i) + c_3(\rho - \varphi) \qquad c_1, c_2, c_3 > 0 \qquad \textbf{(3.4)}$$

where R is the stock of retained earnings. It incorporates the notion that retained earnings are characterized by imperfect substitutability with the two types of external finance considered here.

The money market can be expressed as follows:

$$D = d_0 + d_1 y - d_2\, i \qquad d_1, d_2 > 0 \qquad \textbf{(3.5)}$$

where D is demand for deposits, which is positively related to income and negatively to the bond rate.[81]

Assuming that output is demand determined, the output market is specified by the following equation:[82]

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[78] The rate of return on retained earnings (φ) is specified in Essay 2.

[79] Rates of return are real rates.

[80] Eq. (3.4) arises from the following reformulation of the initial specification: $\mathrm{R} = \mathrm{m_0} + \mathrm{m_1 y} + \mathrm{m_2}(\rho - \varphi) + \mathrm{m_3}(\mathrm{i} - \varphi) = \mathrm{m_0} + \mathrm{m_1 y} + \mathrm{m_2}(\rho - \varphi) + \mathrm{m_3}(\mathrm{i} - \varphi + \rho - \rho) = \mathrm{m_0} + \mathrm{m_1 y} + (\mathrm{m_2} + \mathrm{m_3})(\rho - \varphi) - \mathrm{m_3}(\rho - \mathrm{i})$.

[81] We assume that total wealth is constant while the rate of return on deposits is exogenously fixed and normalized to zero.

[82] Eq. (3.6) is the result from the following reformulation: $\mathrm{y} = \mathrm{w_0} - \mathrm{w_1 i} - \mathrm{w_2}\,\rho - \mathrm{w_3}\,\varphi = \mathrm{w_0} - \mathrm{w_1 i} - \mathrm{w_2}\,(\rho - \mathrm{i} + \mathrm{i}) - \mathrm{w_3}\,\varphi = \mathrm{w_0} - \mathrm{w_1 i} - \mathrm{w_2}\,(\rho - \mathrm{i}) - \mathrm{w_2 i} - \mathrm{w_3}\,\varphi = \mathrm{w_0} - (\mathrm{w_1} + \mathrm{w_2})\mathrm{i} - \mathrm{w_2}\,(\rho - \mathrm{i}) -$

$$y = e_0 - e_1 i - e_2(\rho - i) + e_3(\rho - \varphi) \qquad e_1, e_2, e_3 > 0 \qquad \textbf{(3.6)}$$

Aggregate demand is negatively related to the bond rate and the spread between the loan and bond rates and positively to the spread between the loan rate and the rate of return on retained earnings. Eq. (3.6) is a modified IS curve when there is imperfect substitution between loans, bonds and retained earnings for borrowers.

Two conditions must be met for a bank lending channel to exist. First, borrowers are not able to fully insulate their real spending from a decline in the availability of bank loans, i.e. loans are imperfect substitutes for other sources of external finance. Second, there are no perfect substitutes for loans in bank portfolios. Respectively, a necessary condition for the operation of the balance sheet channel is the existence of imperfect substitution between borrowers' internal and external finance.

Imperfect substitution implies that the derivatives of loan demand and loan supply with respect to the spreads (coefficients a_2, a_3 and b_2) and the corresponding derivatives of the demand for retained earnings (coefficients c_2 and c_3) are finite and moreover that output demand responds to the spreads (e_2, $e_3 > 0$), as well as to the interest rate. When, on the other hand, loan supply is perfectly elastic with respect to the spread (ρ-i) (i.e. $b_2 \to \infty$) and hence (ρ-i)=0 (i.e. $a_2=c_2=e_2=0$), loans and bonds will be perfect substitutes for either borrowers or banks. In this case, the bank lending channel does not operate, the loan supply function, due to the existence of perfect substitution, cannot be defined separately for banking institutions and the (ρ-i) spread is zero and therefore is not a determining factor in the demand equations for loans, retained earnings and output.

Also, when the demand for retained earnings is perfectly elastic with respect to the spread (ρ-φ) (i.e. $c_3 \to \infty$) and hence (ρ-φ)=0 (i.e. $a_3=e_3=0$), retained earnings will be perfect substitutes for both loans and bonds for borrowers. In this case, the balance sheet channel does not operate.

When the values of the critical parameters of the system of structural equations (i.e. a_2, a_3, b_2, c_2, c_3, e_2, e_3) are not subject to the restrictions specified above, this implies that there is imperfect substitutability between bonds and loans and also between

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$w_3\,\varphi = w_0 - (w_1 + w_2)i - w_2(\rho - i) - w_3(\varphi + i - i) = w_0 - (w_1 + w_2 + w_3)i - w_2(\rho - i) - w_3(\varphi - i) = w_0 - (w_1 + w_2 + w_3)i - w_2(\rho - i) - w_3(\varphi - i + \rho - \rho) = w_0 - (w_1 + w_2 + w_3)i - w_2(\rho - i) - w_3\big((\rho - i) - (\rho - \varphi)\big) = w_0 - (w_1 + w_2 + w_3)i - (w_2 + w_3)(\rho - i) + w_3(\rho - \varphi)$.

internal and external sources of finance, and the bank lending and balance sheet channels are both operational.

The system of Eqs. (3.1) to (3.6) can be reduced to a set of three equations that can be used as a basis for assessing the potency of both the bank lending and balance sheet channels. The first of these equations represents an inverted loan supply function, the second is an inverted demand function for retained earnings and the last combines the loan demand function with the equilibrium conditions in the money and output markets.

Bank loans are an important source of funding for firms. Monetary policy variations could have significant effects on financing decisions of firms and investment, through changes in loan supply, especially for borrowers with significant dependence on bank loans. Thus, identification of the loan supply function would enable an assessment of the importance of the lending channel. We express Eq. (3.2) in an equivalent way, as an inverted loan supply function:

$$\rho - i = -b_0/b_2 - (b_1/b_2)D + (1/b_2)L \qquad \textbf{(3.7)}$$

Based on Eq. (3.7), we are able to directly identify the structural parameters of the loan supply function by testing the restriction that $b_2 \to \infty$. If $b_2 \to \infty$, loan supply would be perfectly elastic with respect to the interest rate spread. In this case, as already noted, the loan supply function is not defined, the two rates on loans and bonds are equal, $\rho = i$, and the bank lending channel will be non-operational.

Eq. (3.4) can be solved for $(\rho - \varphi)$ as a function of L, R and $(\rho - i)$:

$$\rho - \varphi = -c_0/c_3 - (c_1/c_3)y + (1/c_3)R + (c_2/c_3)(\rho - i) \qquad \textbf{(3.8)}$$

Under conditions of perfect substitutability between the two sources of external finance, i.e. loans and bonds, the bank lending channel does not operate and the spread $(\rho - i)$ drops from the equation (i.e. $c_2 = 0$). Perfect substitutability, on the other hand, between loans and retained earnings (i.e. $c_3 \to \infty$) implies that the spread $(\rho - \varphi)$ is zero and this time the balance sheet channel does not operate.

Finally, we solve Eq. (3.1) for the spread $(\rho - \varphi)$:

$$\rho - \varphi = a_0/a_3 + (a_1/a_3)y - (1/a_3)L - (a_2/a_3)(\rho - i) \qquad \textbf{(3.9)}$$

and Eq. (3.5) for the bond rate:

$$i = d_0/d_2 + (d_1/d_2)\,y - (1/d_2)D \quad \textbf{(3.10)}$$

Substitution of Eqs. (3.9) and (3.10) into Eq. (3.6) yields the following equation:

$$y = [(e_0 - e_1\, d_0/d_2 + e_3 a_0/a_3) + (e_1/d_2)D - (e_3/a_3)L - e_2(\rho - i)$$
$$-(e_3 a_2/a_3)(\rho - i)]/(1 + e_1 d_1/d_2 - e_3 a_1/a_3) \quad \textbf{(3.11)}$$

According to this specification, when there is perfect substitutability between internal and external finance for borrowers (i.e. $a_3 \rightarrow \infty$, $e_3=0$) the loan variable drops from Eq. (3.11) and the balance sheet channel will not work, while when loans and bonds are perfect substitutes for borrowers (i.e. $a_2=0$, $e_2=0$), the spread (ρ-i) drops from the equation and the irrelevance of the bank lending channel is established.

Through the system of the three Eqs. (3.7), (3.8) and (3.11), our aim is to examine the operation of the bank lending and balance sheet channels following a monetary policy shock. To recapitulate, Eq. (3.7) captures the structural parameters of the loan supply function under conditions of equilibrium in the loan market, Eq. (3.8) captures the parameters of the demand function for retained earnings when there is equilibrium in the market for retained earnings and the last quasi-reduced form Eq. (3.11) describes equilibrium in the loan, output and money markets (demand side).

3.3.2. The amplifying effect of monetary policy

Both the bank lending and the balance sheet monetary transmission channels have been shown to amplify monetary policy shocks to the economy. The bank lending channel, whose existence is based on credit market imperfections caused inter alia by asymmetric information, makes monetary policy more expansionary than in the IS-LM model (Bernanke and Blinder, 1988). In the context of the model proposed by Bernanke and Blinder for analyzing the bank lending channel, the loan market plays a central role in amplifying monetary impulses, which can influence aggregate demand, not only through interest rates as in the traditional interest rate channel, but also through its impact on the supply of bank loans, assuming that these loans are imperfect substitutes with debt securities (bonds) for borrowers and banks. Thus, when monetary policy is tightened, the bank loan supply schedule shifts up and to the left, which complements the interest-rate induced effect on aggregate demand.

Whilst the bank lending channel analyzes the impact of monetary policy shocks on the supply of loans by depository institutions, the balance sheet channel focuses on the potential impact of shocks on firms' balance sheets and their ability to borrow. Thus, a monetary shock that causes a rise in interest rates worsens borrowers' financial conditions and increases the wedge between the cost of external and internal finance, which reduces firms' loan demand. This mechanism (balance sheet channel) reinforces the initial effects on aggregate economic activity.

Although the bank lending and the balance sheet channels are theoretically different, they both incorporate a key fundamental, the financial accelerator. The financial accelerator hypothesis states that information costs that arise from imperfect/asymmetric information between borrowers and lenders alter the costs of firms' financing that have significant consequences on output, amplifying the effect of monetary policy. Output responses become amplified by the operation of the bank lending and the balance sheet channels. Below we show this by using the model consisting of Eqs. (3.7), (3.8) and (3.11). An important result is that the amplification is much stronger if both channels are in operation compared to the case where only one plays a role in monetary transmission.

In particular, in case where the bank lending and the balance sheet channels are operational, the above system of equations may be written in matrix notation as follows: AX=BZ, where:

$$\mathrm{A} = \begin{pmatrix} 1 & 0 & 0 \\ -c_2/c_3 & 1 & c_1/c_3 \\ e_2 + e_3 a_2/a_3 & 0 & 1 + e_1 \mathrm{d}_1/d_2 - e_3 a_1/a_3 \end{pmatrix}$$

$$\mathrm{B} = \begin{pmatrix} -b_0/b_2 & 1/b_2 & 0 & -b_1/b_2 \\ -c_0/c_3 & 0 & 1/c_3 & 0 \\ e_0 - e_1\, d_0/d_2 + e_3 a_0/a_3 & -e_3/a_3 & 0 & e_1/d_2 \end{pmatrix}$$

$$\mathrm{X} = \begin{pmatrix} \rho - i \\ \rho - \varphi \\ Y \end{pmatrix} \qquad \mathrm{Z} = \begin{pmatrix} Con \\ L \\ R \\ D \end{pmatrix}$$

In this case the effect of monetary policy on output is given by the derivative (dY/dD), which is the element in the third row and fourth column of the matrix $A^{-1}B$. This effect is shown in Table 3.2, line 1.

If only the balance sheet channel is operational, the A and B matrices become:

$$A = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & c_1/c_3 \\ 0 & 0 & 1 + e_1 d_1/d_2 - e_3 a_1/a_3 \end{pmatrix}$$

$$B = \begin{pmatrix} 0 & 0 & 0 & 0 \\ -c_0/c_3 & 0 & 1/c_3 & 0 \\ e_0 - e_1\, d_0/d_2 + e_3 a_0/a_3 & -e_3/a_3 & 0 & e_1/d_2 \end{pmatrix}$$

and the effect of monetary policy on output, shown in Table 3.2, line 2, is now smaller since the amplification mechanism is constrained from the non-operation of the bank lending channel.

Finally, if neither the balance sheet channel nor the bank lending channel are operational, the A and B matrices become:

$$A = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 + e_1 d_1/d_2 \end{pmatrix} \qquad B = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ e_0 - e_1\, d_0/d_2 & 0 & 0 & e_1/d_2 \end{pmatrix}$$

and the effect of monetary policy on output is limited further, as shown in Table 3.2, line 3, and this indicates that we have no amplification effects at all when there is not any component of the credit channel at work.

Table 3.2: The amplifying effect of monetary policy through the operation of monetary transmission channels

Channels in operation	Effect of expansionary monetary policy on output (dY/dD)
Interest rate, bank lending and balance sheet channels	$A1 = \dfrac{e_1 + (e_2 + e_3 a_2/a_3) d_2 (b_1/b_2)}{d_2 + e_1 d_1 - (e_3 a_1 d_2)/a_3}$
Interest rate and balance sheet channels	$A2 = \dfrac{e_1}{d_2 + e_1 d_1 - (e_3 a_1 d_2)/a_3} < A1$
Interest rate channel	$A3 = \dfrac{e_1}{d_2 + e_1 d_1} < A2$

Source: Author's calculations

3.4. The recent financial crisis period: some stylized facts

The liberalization of financial markets, the stronger relationship between banking institutions and financial markets and the deregulation of the US mortgage markets in the 1980s, among others, reinforced the effects of asset price variations on the real economy. In addition, financial innovations (e.g. advancements in information technology which allow access to credit markets for institutions that were excluded) in conjunction with the role of institutional investors in the last decade have weakened the potency of the credit channel. In this section, we present some stylized facts for the operation of the monetary transmission channels, especially after the global financial crisis, before we proceed to the analysis of the empirical results in the next section. The recent subprime mortgage crisis that began in the U.S. in 2007 and evolved into a global financial crisis after 2008, brought out the significant relationship between capital market imperfections and investment that can be analyzed in the context of the operation of the credit channel. Capital market imperfections contribute to the reinforcement and propagation of monetary shocks to the real economy.

During a crisis period, adverse effects are expected to get strengthened through the operation of the credit channel. Lower bank liquidity restricts the banks' ability to provide new loans, while banking institutions tighten their credit standards. This can provoke a decrease in real investment, spending and production. Also, a shock can cause a reduction in borrowers' net worth. This happens due to the decrease in the value of their assets that can be used as collateral, which amplifies the negative effects on aggregate economic activity. These effects are reinforced due to greater information asymmetries between borrowers and lenders that prevail during the crisis period.

The recent global financial crisis had as adverse consequences a great amount of non-performing loans for the banking institutions and a decrease in the available credit for banks and borrowers. During the crisis period, according to Gertler and Kiyotaki (2010), there was "a significant disruption of financial intermediation".[83] The monetary authorities have proceeded in implementing a series of unconventional monetary policy measures, which had not been used so extensively in the past, aiming

[83] See also Brunnermeier (2009).

to the reinforcement of credit markets by improving the credit constraints that financial and non-financial borrowers were facing.[84] In this direction, in the U.S., the FED adopted a series of actions, which were not aimed at the short-term interest rates.

The Federal Open Market Committee (FOMC), in the period after the collapse of Lehman Brothers (September, 2008) proceeded to a series of credit policy measures aiming to reinforce liquidity in response to the financial crisis. In particular, the FED increased direct lending in financial and non-financial markets (e.g. markets in commercial paper and mortgage-backed securities) and imperfectly secured lending (e.g. purchases of agency debt) to bank and non-bank financial institutions, which were able to borrow at a discount by providing private debt as guarantees.[85] Also, it lowered the target for the Federal funds rate to its effective lower bound.

Based on these actions, the FED accomplished to increase the prices of securities, reduce their yields[86] and improve investors' balance sheet conditions. Thus, through the operation of the balance sheet channel, the FED aimed to reverse the disastrous crisis effects. However, the FED took a part of private credit risk. As a result, the credit default swaps spreads of banking institutions and of the above markets fell substantially after the FED's capital injections. Moreover, the huge amount of capital contributed to a historical decrease in interest rates. As can be shown in Figure 3.2, the monetary authorities reduced the Federal funds rate that reached the zero lower bound,[87] where it remained until late 2015.[88]

[84] The introduction of quantitative easing was crucial during the turbulent period. Many researchers provide evidence for the effectiveness of the unconventional policy measures that were taken so as to mitigate the disastrous effects of the recent financial crisis in the U.S. (see Baumeister and Benati, 2013; Chen et al., 2016).

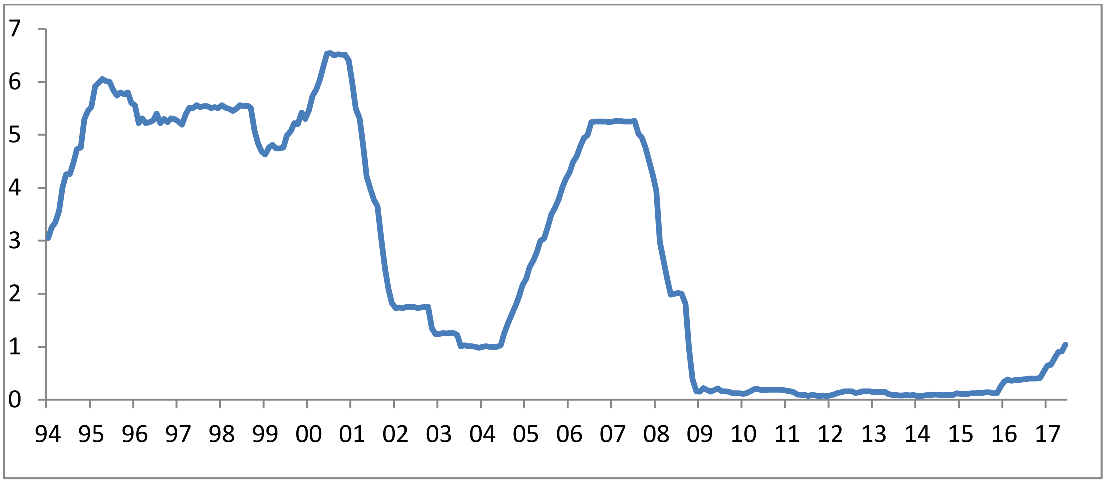
[85] Moreover, in September 2011, the FED announced the Maturity Extension Program (MEP), which involved the purchase of $400 billion of long-term Treasury securities (and the sale of an equal amount of short-term Treasury securities), aimed to increase their price and decrease the long-term interest rates. This process was expected to have a positive influence for borrowers without increasing the balance sheet of the Central Bank. In June 2012, the program was expanded to an additional $267 billion.

[86] See Hamilton and Wu (2012) for further details.

[87] This caused a limitation in the use of the basic instrument for the conduct of monetary policy (see Becker and Ivashina, 2014).

[88] In the same direction, the US banks prime loan rate was also reduced significantly and there were periods during which it turned into negative values.

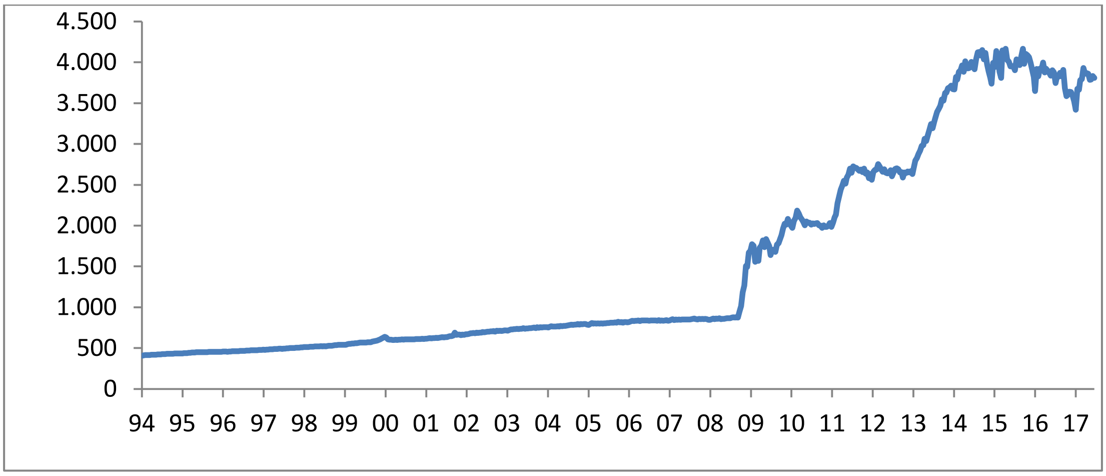
Figure 3.2: The effective federal funds rate (in percent)



Source: Federal Reserve Economic Data

The FED magnified its balance sheet through quantitative easing and the various programs (especially through the purchase of securities) aiming to reinforce liquidity after the inception of the crisis. The FED balance sheet increased from 6 percent to almost 30 percent of GDP in the mid of 2014. Due to this increase, there was a large expansion of the monetary base. Figure 3.3 shows the evolution of the monetary base during the sample period and its expansion to exceptional levels after September 2008.

Figure 3.3: US monetary base (in billions of USD)



Source: Federal Reserve Economic Data

Furthermore, there was significant support to the financial institutions by the US government at the end of 2008, through equity injections, debt guarantees and new loans, so as to secure their operation, deter potential bankruptcies and reinforce the financial system. This support was necessary because the cost of market funding had skyrocketed during the crisis period, provoking liquidity restrictions in the banking industry. The Troubled Asset Relief Program (TARP) or the Term Auction Facility (TAF), among others, contributed to the stability of the banking system -by improving market liquidity- and to the enhancement of economic activity. The fiscal authorities also undertook a part of the private sector credit risk due to the unconventional measures, such as direct lending in credit markets. In conclusion, the monetary policy liquidity facilities to the US banking industry were designed to succeed through the operation of financial markets, with the banking industry having no leading role in this process.

In particular, the TARP provided the ability to the US government to purchase “troubled” assets and equity from US financial institutions, aiming to mitigate the consequences of the subprime mortgage crisis of 2007. A prerequisite for this, was the restoration of trust to the banking system. The total amount of funding was $441.7 billion. The Treasury Department’s Capital Purchase Program (CPP) and the Federal Deposit Insurance Corporation’s Temporary Liquidity Guarantee Program (TLGP) were the main axes of the TARP. Through the CPP, the Department of the Treasury could purchase up to $250 billion of bank senior preferred stock and equity warrants, in order to enhance the liquidity in the US economy through banking institutions. The TLGP improved liquidity in the interbank lending market. Its aim was to restrict the cost of funding of the banking institutions so that the bank lending process would continue normally for consumers and businesses, and to improve banks’ confidence and liquidity by providing the necessary guarantees for newly issued senior unsecured debt.[89]

The implementation of these assistance programs aimed to support bank balance sheets, avoid potential bankruptcies, and prevent possible contagion effects, in order to reverse the unfavorable economic conditions that prevailed after the US subprime crisis. Moreover, the improvement of liquidity in the real economy by enhancing borrowers' financial conditions and by restricting the increase of the cost of external finance was necessary in order to overpass the negative impact of the crisis. In conclusion, the main purpose of these measures was to prevent the propagation and

[89] Federal Deposit Insurance Corporation Press Release, 21st of November, 2008.

intensification of the crisis effects through the operation of the bank lending and balance sheet monetary transmission channels, and so to contribute to the subsequent recovery of aggregate economic activity.

Following the outbreak of the global financial crisis in 2008, many researchers have sought to examine the operation of the bank lending channel, taking into account new data originating in international financial markets. Nevertheless, there is no consensus in the empirical literature about the effectiveness of this channel in the U.S. during and after the crisis period.[90] There are studies that provide evidence for the existence of the bank lending channel during the recent crisis period (see e.g. Gambacorta and Marques-Ibanez, 2011). These studies are mainly utilizing bank specific characteristics and not data in aggregate form, in order to study the operation of the channel. Also, the robustness of their results is controversial due to the fact that they do not examine pre-crisis and post-crisis periods separately. However, the majority of the studies in this field of research show that the potency of the bank lending channel has diminished in the last decades (see e.g. Altunbas et al, 2009).

During the last two decades, there was substantial financial deregulation in the banking system. The strong competition between banking institutions led them to resort to alternative and riskier sources of finance, by expanding their activities to the provision of new financial products. Banks were selling their loans in secondary financial markets in order to reduce their credit risk. The extension of financial instruments such as the growth of securitization, the remarkable development of stock, covered bond and credit default swaps markets, among other financial markets, provided alternative market-based financing sources for the banking system, increased its dependence on financial market conditions and contributed to the reduction of credit supply effects after a monetary policy change. Banks are now more independent from the central bank. Thus, interdependence between banks and financial markets strengthened significantly in the last years, with unpredictable consequences during periods of financial distress.

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[90] The results diverge based on bank balance sheet characteristics that are used in order to examine the existence of the bank lending channel. A number of studies show that the bank lending channel in the U.S. is operative only for small firms which are not able to resort to alternative non-deposit sources of funding, such as asset-backed securities, certificates of deposits and/or covered bonds.

US home mortgage markets were the first form of securitization that was developed in the 1970s.[91] Afterwards, various assets in credit markets were securitized, especially in the second half of the 1990s, with significant effects on monetary policy tools. In the 2000s, there was a strong movement from bank borrowing to securities. The degree of asset substitutability has strengthened substantially in financial markets. Thus, securitization allowed illiquid financial assets to enter financial markets after their transformation into marketable securities. In particular, securitization provided easier access to more liquid assets for banking institutions and contributed to the increase in credit supply to the real economy. It also contributed to the development of the shadow banking system, which substituted bank lending by lending from securities markets and provided borrowers with credit from alternative non-bank sources, which are more accessible than bank credit. Thus, the effectiveness of the bank lending channel was restricted significantly.

According to Altunbas et al. (2007), the role of banks has changed from “originate to hold” to “originate, repackage and sell”, due to the growth of securitization activity. This change has also affected the effectiveness of the bank lending channel, by restricting the basic bank role, which is liquidity transformation. The authors provided evidence that securitization increased bank liquidity and did not allow banks to reduce loan supply after a monetary tightening.[92] In this respect, Trichet (2009) and Ciccareli et al. (2015) argue that the non-operation of the bank lending channel is possibly attributed to the restricted dependence on bank credit supply. Only 20 percent of external financing is derived through bank loans (the corresponding percentage in the Euro area is almost 70 percent). Additionally, the largest part of corporate equity is traded in financial markets.

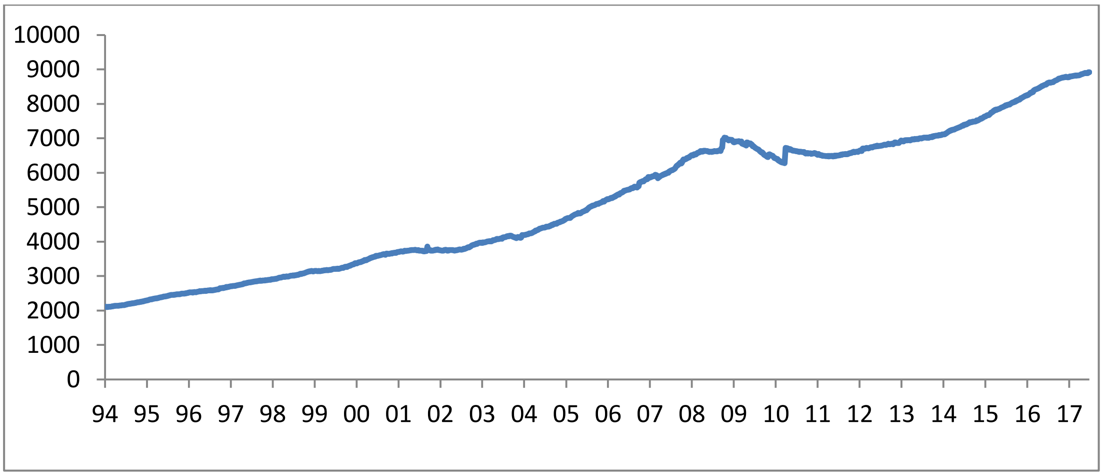
In this direction, Figure 3.4 presents total loans and leases by all commercial banks in the U.S. in the period from 1994:Q1 to 2017:Q2. We observe that the series was increasing steadily, with the exception of the last year of the financial crisis, where loans receded slightly. This reduction in bank loans can be attributed to a decrease in bank loan supply and/or in borrowers' loan demand, as borrowers need less lending or

[91] Loutskina and Strahan (2009) claim that the expansion of the mortgage secondary market fostered by securitization in the U.S. has restricted the operation of the bank lending channel.

[92] Cohen-Cole et al. (2008) argue that total lending was not reduced after the onset of the crisis due to existing loan commitments, lines of credit and securitization that enhanced bank balance sheet conditions.

use internal finance during a crisis period. Thus, there was no significant decline in total loans during the recent recession period, which is a sign for the non-operation of the bank lending channel.[93]

Figure 3.4: Loans and leases in bank credit: All commercial banks (in billions of USD)



Source: Federal Reserve Economic Data

As described above, firms had easier access to credit through market-based financial instruments during the last decades. Through securitization, borrowers were able to substitute bank lending and derive credit through market financing when the credit standards became stricter after a monetary tightening. Moreover, securitization had limited the screening of borrowers by banking institutions, making credit available more easily.

However, the weaker macroeconomic conditions that prevailed after the recent financial crisis, and the significant intensification of information asymmetries in financial markets, restricted borrowers' net worth, while their default rates increased, with adverse effects for bank and borrower balance sheets (Foglia et al. 2011). Banking institutions wrote off a very large amount of "bad" loans after the inception of the crisis, with direct negative effects for their balance sheets. These conditions amplified the need for external financing due to the reduction of internal cash flows. This in turn increased the cost of external finance -especially for borrowers who faced greater financial constraints- and restricted their access to credit. Therefore, through the balance sheet channel or the financial accelerator effect, the consumption and

[93] Chari et al. (2008) show that there was no reduction in bank credit to non-financial corporations and individuals during the financial crisis in the U.S..

investment decreased more intensely, magnifying the initial crisis effects on aggregate economic activity.

Thus, firms in the U.S. became more dependent on external finance because access to internal finance was more difficult due to the restriction of their net worth. Simultaneously, the cost of borrowing increased when the balance sheets of the borrowers were getting worse. This situation, where there is a heightened dependence on external financing while the cost of external finance rises, describes the financial accelerator mechanism.

Aysun and Hepp (2011) provide evidence for the operation of the balance sheet channel. They point out that securitization reinforces the effectiveness of monetary policy, through its effect on the balance sheet channel. In addition, Igan et al. (2017) by using a Factor-Augmented Vector Autoregression model argue that the balance sheet channel is a significant part of the monetary policy transmission mechanism in the U.S. in the pre-crisis period (1990:Q1-2008:Q2). On the same line, Duchin et al. (2010) provide evidence for a significant reduction in the amount of external finance during the subprime mortgage crisis in the U.S., which substantially restricted corporate investment, especially for non-financial firms that had low cash reserves or high net short-term debt, were financially constrained, or operated in industries with strong dependence on external finance. This constitutes evidence for the operation of the balance sheet channel. Finally, Ciccareli et al. (2015), examining the period 1992:Q3-2013:Q1 for the U.S. show that the effect of a monetary policy shock on GDP and prices is strengthened only through the balance sheet channel. They provide evidence that the bank lending channel was not operational as regards business loans during the sample period and that the balance sheet channel was the only transmission mechanism, which amplified monetary policy shocks on real economic activity.

3.5. Empirical evidence

Based on the theoretical structural relationships developed in Section 3 (Eqs. (3.1) to (3.6)), we investigate empirically the operation of the bank lending and balance sheet channels in the U.S., by using Johansen multivariate cointegration analysis.[94] In particular, we identify the equilibrium relationships included in our model from a

[94] See among others Johansen and Juselius (1990); Johansen (1988, 1991).

VEC model and test appropriate restrictions on estimated cointegrating vectors that pertain to the existence of the bank lending and balance sheet channels.

The three-equation model derived above (Eqs. (3.7), (3.8) and (3.11)) and used for assessing theoretically the magnifying effect of monetary policy on real economic activity when one or two monetary transmission channels are in operation, is not suitable for empirically testing the existence of the two components of the credit channel, since it is not possible to identify loan supply shifts in the model. It is therefore necessary to reformulate it, in order to achieve exact identification of the equilibrium parameters, in conformity with Pesaran and Shin's (2002) theory of identification of an equilibrium structure in a VEC model. Thus, based on the system of structural equations (Eqs.(3.1) to (3.6)), we specify an alternative configuration of equilibrium relationships that are amenable to estimation.

More specifically, we substitute Eqs. (3.1) and (3.2) in Eq. (3.3) and solve for the spread (ρ-i), as follows:

$$\rho - i = f_0 + f_1 y - f_2(\rho - \varphi) - f_3 D \qquad f_1, f_2, f_3 > 0 \qquad \textbf{(3.12)}$$

where $f_0 = (a_0 - b_0)/(a_2 + b_2)$, $f_1 = a_1/(a_2 + b_2)$, $f_2 = a_3/(a_2 + b_2)$,

$f_3 = b_1/(a_2 + b_2)$,

Solving Eq. (3.4) for the spread (ρ-φ), we obtain:

$$\rho - \varphi = g_0 - g_1\, y + g_2 R + g_3(\rho - i) \qquad g_1, g_2, g_3 > 0 \qquad \textbf{(3.13)}$$

where $g_0 = -c_0/c_3$, $g_1 = c_1/c_3$, $g_2 = 1/c_3$, $g_3 = c_2/c_3$

Finally, substitution of Eq. (3.10) into Eq. (3.6) yields:

$$y = h_0 + h_1 D - h_2(\rho - i) + h_3(\rho - \varphi) \qquad h_1, h_2, h_3 > 0 \qquad \textbf{(3.14)}$$

where $h_0 = (e_0 - e_1\, d_0/d_2)/(1 + e_1 d_1/d_2)$

$h_1 = (e_1/d_2)/(1 + e_1 d_1/d_2)$

$h_2 = (e_2)/(1 + e_1 d_1/d_2)$

$h_3 = (e_3)/(1 + e_1 d_1/d_2)$

Therefore, the equilibrium relationships on which we focus on are Eqs. (3.12), (3.13) and (3.14). In case we identify empirically the existence of these three equations, this implies the operation of the bank lending and balance sheet channels in addition to the interest rate channel. In case there are no information asymmetries in the credit and the loan markets, the identification of a distinct loan demand function is not possible because loans and bonds are perfect substitutes for borrowers and (ρ=i). Similarly, loans and bonds are perfect substitutes in bank portfolios. Under these conditions, only two equilibrium relationships can be identified, i.e. Eqs. (3.13) and (3.14):

$$\rho - \varphi = g_0{'} - g_1{'}\, y + g_2{'}R \qquad g_1{'}, g_2{'} > 0 \qquad \textbf{(3.15)}$$

$$y = h_0' + h_1'D + h_2{'}(\rho - \varphi) \qquad h_1{'}, h_2{'} > 0 \qquad \textbf{(3.16)}$$

In this case, of the two components of the credit channel, only the balance sheet channel is operating.[95] If, in addition, there are no information asymmetries in the firms' access to internal and external finance, loans and retained earnings are perfect substitutes and (ρ=φ). As a result, there is a further reduction of the two-equation system to one equation, which is:

$$y = h_0{''} + h_1''D \qquad h_1{''} > 0 \qquad \textbf{(3.17)}$$

As we mentioned in Section 3, perfect substitutability between loans and bonds for banks and borrowers implies that the bank lending channel is not operational. In addition, perfect substitutability between internal and external finance for borrowers renders the balance sheet channel non-operational. Thus, the existence of informational asymmetries is a necessary condition for the operation of both channels. Otherwise, when the channels are not active, the identification of distinct loan demand and supply functions is not possible, while output demand and the demand for retained earnings are not responsive to changes in the spreads.

Thus, in what follows, we will pursue to disentangle shifts in loan supply from shifts in loan demand and identify shifts in the demand for retained earnings in an attempt to quantify empirically the two components of the credit channel. However, internal and external sources of finance have experienced profound changes in the last decades, especially after the financial crisis of 2008, which may have caused significant changes in the transmission of monetary policy. Therefore, we will examine how these changes have manifested themselves as changes in the underlying

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[95] In case, however, loans and retained earnings are perfect substitutes (i.e. ρ=φ), the two equilibrium relationships would be: $\rho - i = f_0{'} + f_1{'}y - f_2{'}D$ and $y = h_0{'} + h_1{'}D - h_2{'}(\rho - i)$ and the bank lending channel, rather than the balance sheet channel, would be operating. This hypothesis is examined and rejected below by testing the appropriate over-identifying restrictions.

equilibrium relationships (Eqs. (3.13), (3.14) and (3.15)), which can take the form of changes in the number of these relationships.

In order to specify the existence of cointegrating relationships among the variables, we estimate an unrestricted vector autoregressive (VAR) model over the entire sample period and over the subperiods, which are determined according to the recursive and breakpoint stability tests. The general reduced form of a VAR (k,p) model with k variables and p lags is:

$$y_t = \delta + A_1 y_{t-1} + A_2 y_{t-2} + \cdots + A_p y_{t-p} + B x_t + e_t$$

where $y_t = [y_{1t}, \dots, y_{kt}]'$ is a $k \times 1$ vector of k endogenous non-stationary variables, $x_t = [x_{1t}, \dots, x_{dt}]'$ is a (dx1) vector of exogenous and/or deterministic variables, $A_1, \ldots A_p$ are kxk matrices of the coefficients of endogenous variables for i = 1,2,...,p, p is the order of the VAR model, B is a k×(d+1) matrix of the coefficients of exogenous variables, e_t is a white noise kx1 vector of error terms and δ is a k×1 vector of intercepts.

Covariance stationarity and integration of order zero, I(0), are necessary conditions for estimating a VAR model in levels. If these conditions are not met, we should perform some additional tests in order to choose the appropriate model specification. When variables are non-stationary and integrated of order d, i.e. I(d), we should test the time series for the existence of long-run relationships (cointegrating relationships). If the series are not cointegrated, we run a VAR model in differences. In case the time series are cointegrated, we estimate a VEC model by using the Johansen (1991,1995) maximum likelihood procedure, so as to specify the cointegrating relationships among the variables. For this purpose, we re-parameterize the VAR model in a VEC form. A VEC model is given by the following form:

$$\Delta y_t = \delta + \Pi y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + B x_t + e_t$$

where $\Pi = \sum_{j=1}^{p} A_j - I_k$, Π is a (k×k) matrix of parameters which capture the adjustment to long-run equilibrium, $\Gamma_i = -\sum_{j=i+1}^{p} A_j$, Γ_i is the matrix of short-run adjustment parameters, p is the order of the VEC model and Δ is the first-difference operator. Γ_i, Π and B are assumed to be constant. Based on the test statistics of Johansen and Juselius (1990) and Johansen (1995), we define the rank r of the matrix

Π, which is the number of stationary linear relations of y_t. The rank of the matrix Π determines the appropriate model specification. In case where all the elements of y_t are stationary in levels, Π will be a full rank kxk matrix and a VAR model in levels is estimated. When the elements of y_t are I(1) and not cointegrated, Π will be a zero-rank matrix and a VAR model in first differences is estimated. In case where the elements are I(1) and cointegrated and the rank of Π is r, Π is a reduced rank matrix ($r<k$) and there must be r cointegrating relationships among them. In this case, the long-run matrix Π can be factorized as a product of two matrices α and β, such that $\Pi=\alpha\beta'$, where α is the matrix of loading factors which capture the speed of adjustment toward equilibrium and β is the matrix of r cointegrating vectors. By using the Johansen cointegration technique, the orthogonalization of β implies a unique estimation of α and β, which satisfies the equation $\Pi=\alpha\beta'$.

Thus, this identification method sets a number of specific restrictions. Pesaran and Shin (2002) criticize this approach claiming that there is no economic theoretical background for its support. More specifically, they argue that, based on Johansen's approach, the necessary r^2 just-identifying restrictions are imposed at the first r eigenvectors. This happens for mathematical convenience and it is not possible to test restrictions predicted by economic theory or other relevant a priori information. Therefore, in order to be able to derive conclusions according to economic theory, it is necessary to impose and examine a number of appropriate restrictions concerning the parameters of the β matrix. The imposition of r^2 restrictions is a necessary and sufficient condition for the exact identification of the cointegrating vectors (r restrictions in each of the r cointegrating vectors), in agreement with specific theoretical economic assumptions**.** By imposing linear over-identifying restrictions on the elements of matrix β, according to the cointegration approach developed by Pesaran and Shin (2002), we are in a position to test the validity of a series of economically meaningful hypotheses, based on the theoretical restrictions developed in Section 3. In this way, we will be able to examine the existence of the bank lending and the balance sheet channels.

We investigate the operation of the bank lending and balance sheet channels in the U.S. over the period from 1994:Q1 to 2017:Q2, by using aggregate data. In the empirical analysis, we use quarterly observations. Bank loans (L), deposits (D) and retained earnings (stock) (R) are end-of-quarter variables, deflated by the consumer price index. These variables and real GDP are expressed in logarithms[96] and are seasonally adjusted.

As for the interest rate/rate of return variables, these are real variables. The real loan rate (ρ) and real bond rate (i) are calculated by subtracting the annual inflation rate from their nominal values, and are expressed as quarterly averages. The inflation rate is computed in terms of the consumer price index as the year-on-year percentage change. The rate of return on retained earnings (φ) is calculated as the ratio of the flow of retained earnings and depreciation to the stock of retained earnings, where for this calculation primary data are used. The main sources of the data are the Federal Reserve Economic Data (FRED) and Quarterly Financial Report (QFR)[97,98] databases. In the appendix, we cite the definitions and sources of all variables.

To start with, we estimate an unrestricted VAR model for the full sample period. The specification of the lag length is based on the Schwarz Information Criterion (SIC). The optimal lag length is equal to 2. We perform the standard diagnostic tests for heteroskedasticity, normality and autocorrelation. Based on these results, we choose the optimal lag to be equal to 6, so as to ensure statistical adequacy, which is necessary to proceed to cointegration analysis and derive reliable estimations. Table 3.3 provides the descriptive statistics of the variables of our model. We observe that skewness and kyrtosis are not near 0 and 3, respectively, which are the standard values for a normal distribution. On the contrary, on the basis of the Jarque-Bera (JB) test, the null hypothesis of a normal distribution cannot be rejected. The results in

[96] Logarithmic values are used due to large variations in some of the time series, which also allow us to correct for potential heteroskedasticity problems (Forte and Pena, 2009).

[97] The QFR database includes quarterly data for all sizes of Manufacturing, Mining, Wholesale, Trade and selected Service Industries. One of the advantages of the QFR data is that they include firms that are publicly traded and firms that are not, while they are available at a quarterly frequency (Oliner and Rudebusch, 1996). Thus, the database captures the behavior of small and large firms (Gertler and Gilchrist, 1994; Bernanke et al., 1996) and permits quantitative estimations of the aggregate implications of credit constraints. Moreover, aggregate time series are available also in disaggregated form, according to firm size class and industry class.

[98] The sectoral classification for QFR data was changed in 2000:Q4. Up to 2000:Q3 the Standard Industrial Classification (SIC) classification was used, while from 2000:Q4 onwards, the North American Industry Classification System (NAICS) classification is followed. As a result of this change, some sectors have been reclassified. In addition, the total across all sectors has been affected as some sectors covered under the previous classification are no longer covered and vice-versa. To deal with the resulting break in the series, these have been spliced, using the relationship of the series for the period for which reporting under both classification schemes is available (2000:Q4-2001:Q2).

Table 3.4 provide evidence that our series are normally distributed, except for the GDP variable in the first subperiod.

Table 3.3: Descriptive statistics

Panel A: Descriptive statistics for the 1st period							
Variable	Obs	Mean	Std. Dev.	Min	Max	Skewness	Kyrtosis
ρ-i	60	0.017	0.012	-0.006	0.039	-0.250	1.832
ρ-φ	60	-0.026	0.026	-0.079	0.064	0.418	4.088
y	60	12601	1651	9748	14991	-0.157	1.784
R	60	1749	404	1159	2558	0.782	2.495
L	60	1181	165	884	1589	0.417	2.619
D	60	5070	1093	3682	7355	0.411	1.926
Panel B: Descriptive statistics for the 2nd period							
Variable	Obs	Mean	Std. Dev.	Min	Max	Skewness	Kyrtosis
ρ-i	34	0.008	0.007	-0.004	0.019	-0.280	2.011
ρ-φ	34	-0.029	0.023	-0.075	0.018	0.200	2.552
y	34	15632	828	14355	17031	0.102	1.754
R	34	3223	420	2375	3723	-0.715	2.141
L	34	1497	247	1183	1889	0.319	1.733
D	34	8895	1011	7488	10494	0.162	1.525

Table 3.4: Jarque-Bera test results

Variable	1st period	2nd period
ρ-i	4.035 (0.132)	1.831 (0.400)
ρ-φ	4.709 (0.094)	0.511 (0.774)
y	3.944 (0.139)	2.256 (0.323)
R	6.763 (0.033)	3.945 (0.139)
L	2.107 (0.348)	2.849 (0.240)
D	4.576 (0.101)	3.227 (0.199)

Note: The table presents the JB test statistics. Numbers in parenthesis are probabilities to accept the null hypothesis at the 5% significance level.

As a preliminary step, we test the time series for stationarity applying the Phillips-Perron (PP), and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) standard unit root tests, over the entire sample period.[99] Moreover, we examine the stationarity properties of the series in levels applying a modified augmented Dickey-Fuller unit root test, which allows the specification of the breakpoint endogenously from the data.[100] We test the null hypothesis that the series has a unit root with a possible intercept break, versus the alternative that the series is stationary with a breakpoint.

The lag structure is specified based on the Schwarz criterion. We consider that a time series has a unit root, when at least two of the above three tests show the existence of a unit root at a 5% significance level. We find that all variables in levels have a unit root. In this case, we calculate first-differences in order to achieve stationarity and repeat the unit root tests. The first differences are stationary. We conclude that our variables are integrated of order one, i.e. I(1).

[99] In testing for stationarity, the KPSS test is more reliable for small samples. The null hypothesis of the KPSS test is that the series is stationary, in contrast to the PP unit root test where the null hypothesis is that the series has a unit root.

[100] Perron (1989) has shown that this approach is more robust, in case where the variables are trend stationary, while standard unit root test results are biased toward the non-rejection of the null hypothesis when there is a structural break in the mean of a stationary time series.

We then proceed to examine for cointegration, based on the Johansen maximum eigenvalue test (1995),[101,102] so as to estimate the number of cointegrating relationships among the non-stationary time series in our sample. We find evidence for two cointegrating relationships among the variables.

Before proceeding to estimation, we need to test for temporal instability which, if existent, may bias seriously our estimates. The recent financial crisis could be a case in point. Thus, we run a series of stability tests to identify potential structural breakpoints. In particular, plots of the restricted cointegrating relationships after imposing just-identifying restrictions (Figure 3.5) and the one-step forecast (probability) and recursive residuals stability tests for the system as a whole (Figure 3.6) indicate abnormal variations in 2008:Q4. This could be a sign of a possible break. This instability is also verified by the Bai-Perron breakpoint test, which determines the structural breakpoints endogenously from the data.[103] The results show that there was a structural change after the financial crisis of 2008 in the U.S., which represents a shift in the underlying financial structure. Thus, we set the breakpoint in 2008:Q4[104] and split our sample, in order to ensure parameter constancy. Moreover, a dummy variable is included in the VEC model in the first subperiod, in order to capture the effects of abnormal variations in 2002:Q3.[105,106]

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[101] More specifically, we specify the number of cointegrating relationships according to the maximum eigenvalue test results, at the 5% significance level. The maximum eigenvalue test is $\lambda_{max}= -T \ln (1-\hat{\lambda}_{r+1})$, r=0,1, ..., k-1. The H_o hypothesis is $r \leq r_0$ for r_0=0,1,...,k-1, where k is the number of variables. The H_1 hypothesis assumes that there are r_0+1 cointegrating vectors. We include a constant (intercept) in each cointegrating equation, which reflects in a more plausible way the generating mechanism of the data.

[102] Lütkepohl et al. (2001), based on Monte Carlo simulations, compare the maximum eigenvalue and the trace tests for the specification of the cointegrating rank of a VAR process. They provide evidence that the trace test has superior power performance relative to the maximum eigenvalue test in some situations. However, they show that the trace test tends to have more distorted size in small samples in comparison with its competitor. Juselius (2006) also argues that size and power distortions could arise with the application of the trace test when the sample is small. Since in our case the sample is relatively small, we prefer the maximum eigenvalue test for the determination of the cointegrating rank.

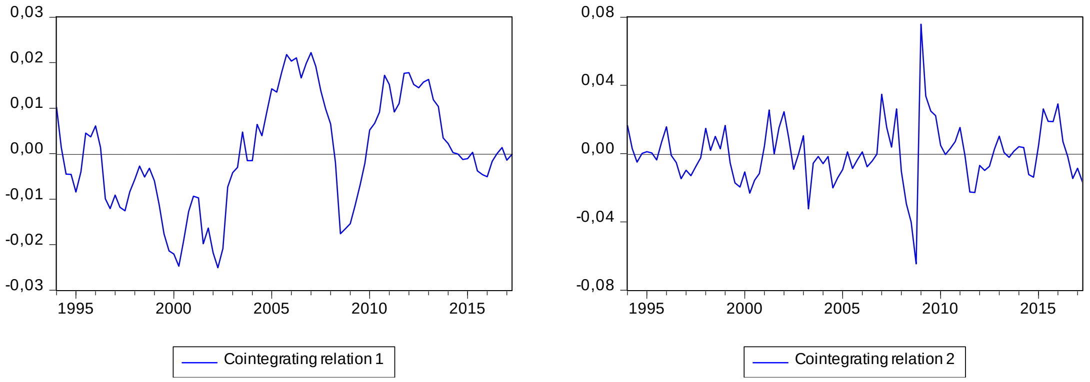
[103] The Bai-Perron test allows the error distribution to vary across breaks.

[104] Our findings are also robust when we test for the potential breakpoint based on the Chow test.

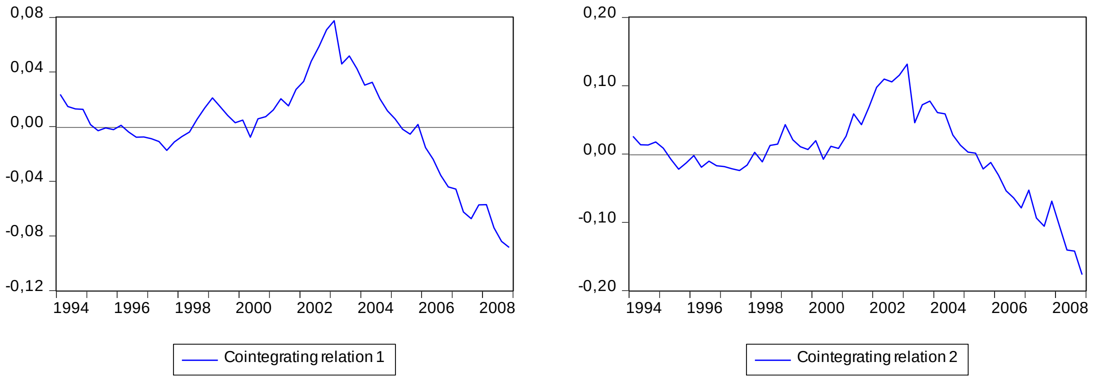
[105] We examine the residuals of the initial VEC model, and if we find outliers greater than 3 standard deviations, then we include a series of point dummy variables -as exogenous variables- to capture specific abnormal events during the period under study. Our results are robust to a range of threshold values between 2.5 and 3.5 standard deviations.

Figure 3.5: Plots of the restricted cointegrating vectors

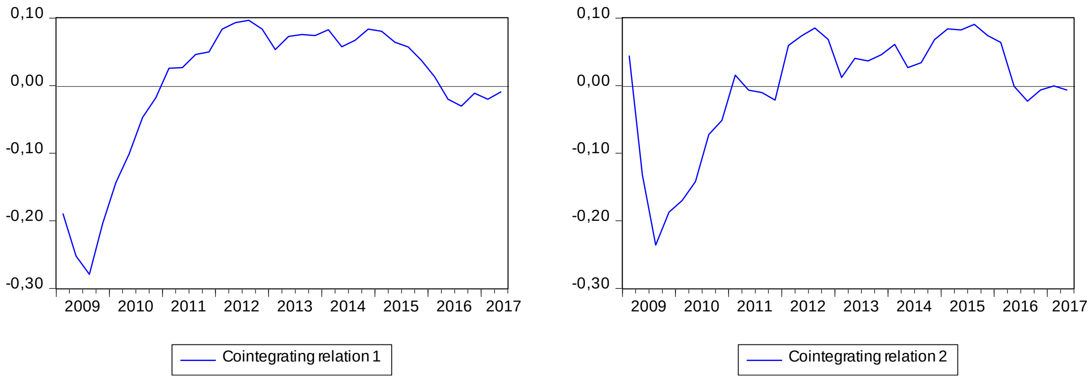
A. 1994:Q1 - 2017:Q2



B. 1994:Q1 - 2008:Q4



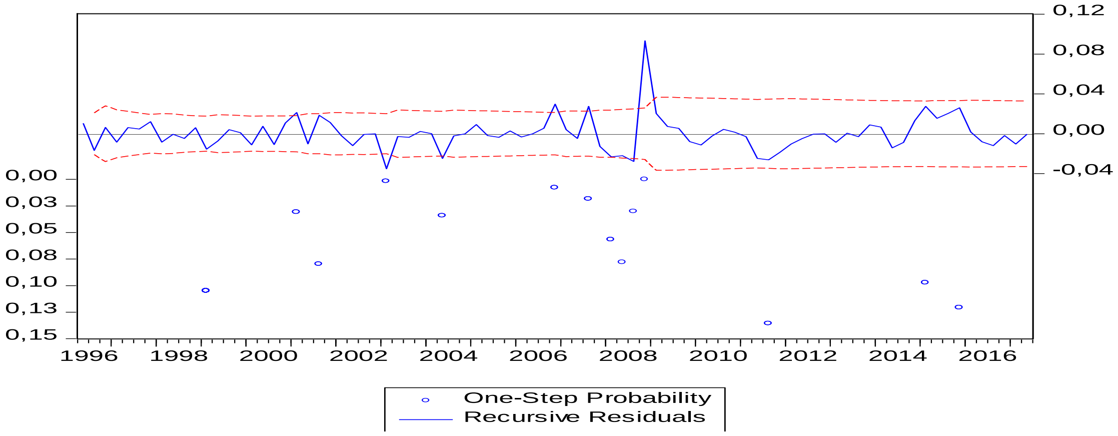
C. 2009:Q1 - 2017:Q2



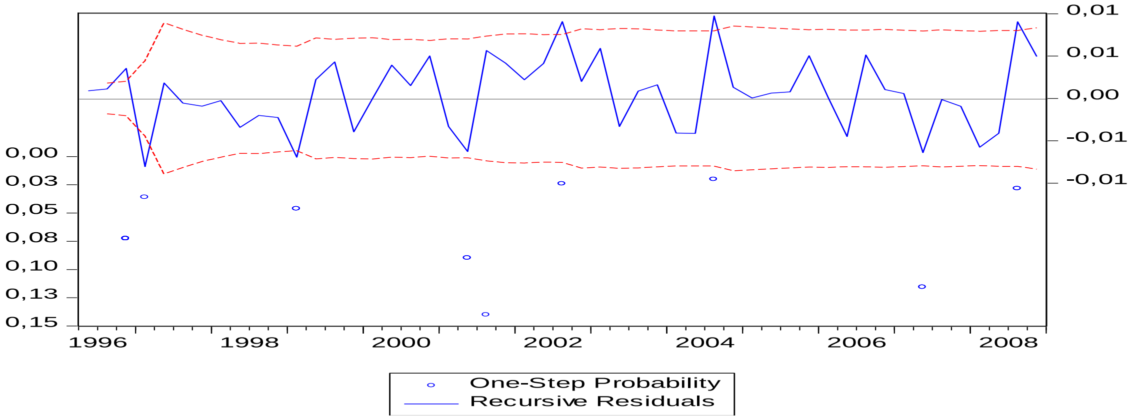
[106] We do not split the sample in 2002:Q3 because there is no structural change with permanent effects, while the size of the sample is not sufficient to obtain reliable results. This breakpoint possibly captures the US stock market downturn in September 2002.

Figure 3.6: One-step probability and recursive residuals stability tests

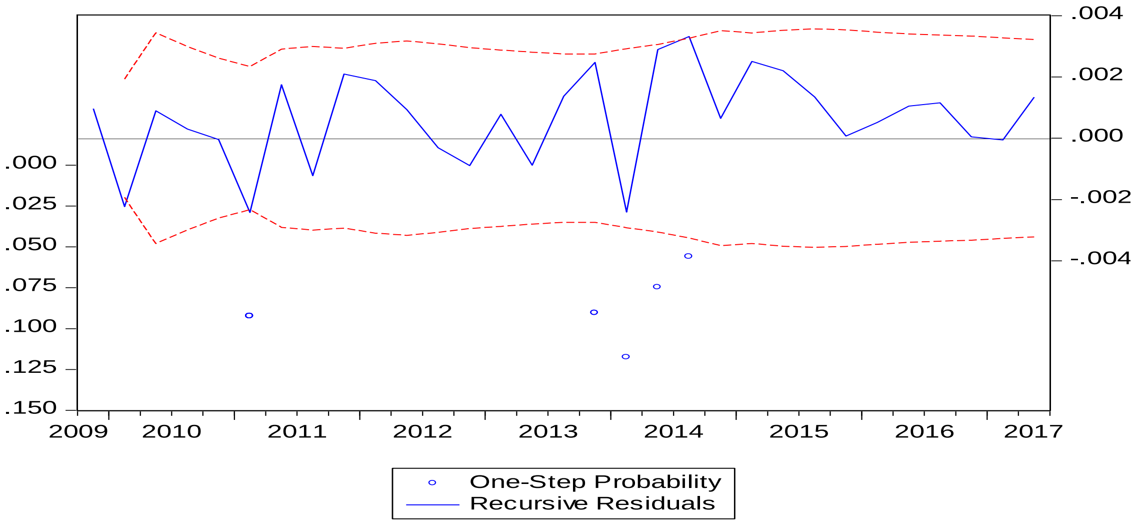
A. 1994:Q1 - 2017:Q2



B. 1994:Q1-2008:Q4



C. 2009:Q1 - 2017:Q2



Once we have split our sample into two subperiods (1994:Q1-2008:Q4 and 2009:Q1-2017:Q2), we estimate VAR models in order to specify the optimal lag length. The optimal length, specified according to the Schwarz criterion, is equal to 2 and 1, for the first and second subperiod, respectively. Diagnostic test results provide evidence that there is no autocorrelation, the residuals are multivariate normal, while there is no heteroskedasticity.

Once again, we run the aforementioned unit root tests but this time in each subperiod. All the variables are also found to be I(1). Results from the unit root tests are presented in detail in Table 3.5. Stability test results, for each subperiod verify that the cointegrating parameters are relatively constant. We perform the Johansen cointegration test on the subsamples. We assume unrestricted intercepts and no trends in the cointegration test and the VAR model. Johansen's maximum eigenvalue test results are presented in Table 3.6, for both subperiods. The cointegration results provide evidence for the existence of only two cointegrating vectors in both subperiods. In this case, we have to examine that only one of the sub-channels of the credit channel is operational in these subperiods, and works additionally to the traditional interest rate channel.

For this purpose, we need to impose a number of over-identifying restrictions in the cointegrating relationships, in order to test the operation of the monetary channels in both subperiods, under conditions of imperfect substitutability between alternative sources of external financing, or between sources of internal and external financing. The restrictions which are imposed to identify the appropriate cointegrating vectors rely on the economic assumptions defined above, in accordance with our theoretical setup. We start by testing the operation of the balance sheet channel. By using the likelihood ratio test of Johansen and Juselius (1994), we test the over-identifying restrictions that lead to the system of equations (3.15) and (3.16) against the exactly-identifying restrictions that underlie the system of equations (3.13) and (3.14).[107]

[107] The standard likelihood ratio test of the over-identifying restrictions follows asymptotically a x^2(k-r) distribution, where k is the number of restrictions and r is the number of cointegrating relationships.

Table 3.5: Unit root test results

Panel A: Unit root test results in the 1st period

Variables	Series in levels			Series in first differences		
	Breakpoint test	KPSS	PP	Breakpoint test	KPSS	PP
ρ-i	0.364	0.094	0.181	0.683	0.095	0.000***
ρ-φ	0.118	0.233	0.039**	0.146	0.187	0.000***
y	0.659	0.942***	0.086**	0.972	0.579**	0.001***
R	0.893	0.843***	0.795	0.669	0.091	0.002***
L	0.861	0.399*	0.731	0.721	0.185	0.082*
D	0.990	0.956***	1.000	0.990	0.656**	0.000***

Panel B: Unit root test results in the 2nd period

Variables	Series in levels			Series in first differences		
	Breakpoint test	KPSS	PP	Breakpoint test	KPSS	PP
ρ-i	0.000***	0.542**	0.682	0.059*	0.131	0.003***
ρ-φ	0.000***	0.271	0.008***	0.000***	0.367*	0.000***
y	0.000***	0.680**	0.993	0.000***	0.210	0.000***
R	0.016**	0.596**	0.196	0.000***	0.443*	0.004***
L	0.000***	0.549**	0.883	0.000***	0.395*	0.142
D	0.000***	0.665**	0.919	0.000***	0.129	0.000***

Note: The table presents the results after applying the breakpoint (p-values), the PP (p-values) and the KPSS (LM- statistics) unit root tests. Period 1 ranges from 1994:Q1 to 2008:Q4 and period 2 from 2009:Q1 to 2017:Q2. *, **, *** denote statistical significance at the 10%, 5%, and 1% level, respectively.

Table 3.6: Cointegration analysis

Panel A: Johansen cointegration test		
Period	1994:Q1 – 2008:Q4	2009:Q1 – 2017:Q2
Number of cointegrating vectors[a]	2	2
Maximum eigenvalue test	27.584 (0.0538)	24.831 (0.1082)

Panel B: Coefficients on cointegrating vector variables[b]				
Period	1994:Q1 – 2008:Q4		2009:Q1 – 2017:Q2	
Variables	Vector1	Vector2	Vector1	Vector2
ρ-i	0.000	0.000	0.000	0.000
ρ-φ	1.000	-1.478 (0.225) [-6.558]	1.000	0.326 (0.013) [25.051]
Y	1.697 (0.258) [6.568]	1.000	1.061 (0.169) [6.256]	1.000
R	-1.224 (0.174) [-7.035]	0.000	-0.742 (0.047) [-15.481]	0.000
L	0.000	0.000	0.000	0.000
D	0.000	-0.792 (0.053) [-14.714]	0.000	-0.481 (0.016) [-29.913]
LR test[c,d]	$x^2(4)$=10.002 (0.040)		$x^2(4)$=4.231 (0.375)	

Note: [a] Numbers in parenthesis are the Mackinnon-Haug-Michelis (1999) probability values to accept the null hypothesis at the 5% significance level.

[b] Numbers in parentheses are asymptotic standard errors, while numbers in brackets are the t-statistics.

[c] Numbers in parentheses are probabilities to accept the over-identifying restrictions.

[d] *,** and *** denote rejection of the null hypothesis at the 10%, 5%, and 1% significance level, respectively.

Table 3.6 reports the maximum likelihood estimates of the over-identified model in both subperiods. The likelihood ratio test is equal to 10.002 (p-value=0.040) and 4.231 (p-value=0.375) in the first and second subperiod, respectively. Based on these test results, we cannot reject the zero restriction on the coefficient of the (ρ-i) spread variable in both subperiods. This implies the existence of perfect asset substitutability for borrowers and banks, and as a result the non-operation of the bank lending channel. Moreover, all the coefficients of the estimated cointegrating vectors are significant and correctly signed in both subperiods. The only exception is the sign of the coefficient of the spread variable (ρ-φ) in the second subperiod. This divergence is possibly attributed to the restricted sample size.[108]

3.6. Conclusions

Monetary policy transmission channels are the main linkages between the financial system and the real economy. Monetary policymakers, besides their basic mandate in keeping inflation at a low level, have a key role in stabilizing economic activity. This can be helped through the operation of the two components of the credit channel, namely the bank lending and the balance sheet channels. A monetary policy shock that causes an increase in the interest rate may also have significant effects on the cost of credit and as a result on bank loan supply and on borrowers' balance sheet conditions. Thus, the exact comprehension of the operation of the bank lending and balance sheet channels, particularly during a crisis period, is necessary so as to properly assess the monetary policy transmission mechanism.

Based on the Bernanke and Blinder (1988) model, we have developed an extended theoretical framework, which is suitable for empirically testing the operation of the bank lending and balance sheet channels simultaneously, by using aggregate data. Assuming the existence of information asymmetries, our model incorporates imperfect substitution between internal and external finance for firms, which is a necessary condition for the operation of the balance sheet channel, beyond the imperfect

[108] To verify the validity of the above results, we also test for the possible operation of the bank lending channel instead of the balance sheet channel, by imposing the appropriate over-identifying restriction (ρ-φ=0) in the system of Eqs. (3.12) and (3.14). The likelihood ratio test results show that we cannot accept the null hypothesis (p-value=0) in both subperiods. which implies that there is imperfect substitution between loans and retained earnings (i.e. ρ≠φ). Thus, we proceed by considering that only the balance sheet channel is operational, since in the first place we have identified the existence of two cointegrating vectors.

substitution between the different components of external finance as in the Bernanke and Blinder model, which is a necessary condition for the operation of the bank lending channel.

Thus, we have succeed to disentangle shifts in loan supply from shifts in loan demand and identify shifts in the demand for retained earnings, in order to be able to quantify the effects of the operation of the monetary transmission channels on real economic activity. We have shown that the operation of the two components of the credit channel amplifies the effect of a monetary policy shift on aggregate output, relative to the case where one or none of the two sub-channels operates.

We have captured the amplifying effects of the credit channel by deploying a system of equilibrium equations, describing firms' financial structure and the equilibrium conditions in the loan and output markets. For this purpose, we have used and estimated our model to determine and test the appropriate theoretical restrictions on equilibrium relationships (cointegrating vectors) that capture the degree of asset substitutability between the components of external finance (loans and bonds) and between internal and external finance and, thus, assess the existence of the credit channel. We have demonstrated that if we identify three equilibrium equations, then the bank lending and balance sheet channels are operational, complementary to the interest rate channel. In case that we find two or one equilibrium relationships, we have shown that only the balance sheet channel or neither of the two channels is in operation, again in addition to the interest rate channel.

Financial developments in the last two decades, and especially the extensive use of market-based financial assets, have increased asset substitutability, providing alternative sources of funding for banks and firms that have changed the potency of the credit channel. Our tests provided no evidence for the operation of the bank lending channel in the U.S. for the periods before and after the financial crisis. The unconventional monetary policy measures that were taken during the recent crisis period contributed decisively to overcoming the potential constraints on bank credit supply and support our findings. Thus, the bank lending channel does not seem to be part of the monetary transmission mechanism.

Only the balance sheet channel is operational in both subperiods. The magnifying effects of the operation of the balance sheet channel could be useful to explain, partially, the persistent negative effects of the restrictive US subprime mortgage crisis of 2007, which evolved to a global financial crisis after the collapse of Lehman Brothers in September 2008.

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Appendix: Data definitions and sources

The dataset begins in 1994:Q_1 and ends in 2017:Q2. Sources of the data are the Federal Reserve Economic Data (FRED) and Quarterly Financial Report (QFR) databases published by the Federal Reserve Bank of St. Louis and the U.S. Census Bureau, respectively. The definition of the data and the corresponding sources are as follows:

- Loans: Commercial and industrial loans, all commercial banks - (FRED)
- Deposits: Deposits, all commercial banks - (FRED)
- GDP: Real gross domestic product, billions of chained 2009 dollars, annual rate - (FRED)
- Retained earnings (stock): Retained earnings of manufacturing, mining and trade corporations - (QFR)
- Retained earnings (flow): Retained earnings of manufacturing, mining and trade corporations - (QFR)
- Depreciation (flow): Depreciation of manufacturing, mining and trade corporations - (QFR)
- Lending rate: Bank prime loan rate - (FRED)
- Bond rate: 10-year government benchmark bond yield - (FRED)
- CPI: Consumer price index, Total all items for the United States, index 2010=1 - (FRED)

Essay 3

Conclusion

The main aim of the present dissertation was twofold. On the one hand, to examine the nexus between sovereign and bank credit risk during the recent Eurozone debt crisis. To do so we focused on changes in the presence and direction of causality between the corresponding CDS spreads in the period before and after the implementation of the PSI program. On the other hand, the aim was to develop a theoretical framework in order to quantify the amplifying effects of a monetary policy shift on aggregate output, through the operation of the bank lending and the balance sheet channels, and also, by specifying a proper definition of the cost of internal finance, to analyze the operation of these monetary transmission channels in the U.S. over the last two decades.

This thesis is composed of three stand-alone essays. More precisely, in the first essay, we investigated the effectiveness of the PSI program in restricting the (linear and nonlinear) contagion effects between sovereign and bank credit risk, by employing daily CDS of eight Eurozone countries and twenty-one banking institutions, over the period January 2009 to May 2014. To our knowledge, this is the first study that uses a nonlinear econometric framework to capture nonlinear dynamics in the relationship between the CDS series, during a period of highly volatile conditions in the Eurozone. For this purpose, we applied the non-parametric causality test of D&P (2006) that allowed us to capture adequately, in a more complex framework, the potential nonlinear structure of the relationship between the time series, without setting any conditions regarding the relationship between them, and consequently, without imposing any model restrictions.

We found that the causal effects running from sovereign CDS spreads to the bank CDS spreads were stronger in both subperiods, before and after the announcement of the PSI. This indicates a public-to-private risk transfer. Nevertheless, linear and nonlinear test results provided evidence that the causal linkages between sovereign and bank credit risk weakened after the PSI, while the persistence and magnitude of lead-lag interactions also declined in the same period. Moreover, we observed that volatility spillovers are a significant reason for the existence of Granger causal relationships. However, the retained interconnections between the CDS series, after first and second moment filtering, imply that the causal linkages between them were not due to simple volatility effects only.

Concerns of contagion due to a restructuring of the Greek debt were the main impulse of initiatives by the European Union and the International Monetary Fund. Thus, we focused on an event such as the PSI, because we considered it as an important breakpoint, with significant effects on the interaction between sovereign and bank credit risk in the Eurozone. It was the first debt restructuring in the Eurozone in contradiction with the promises of politicians that such an event was impossible. Even if a shock occurred in a small country like Greece (according to the Eurostat, the share in total EU GDP was 1.2 percent in 2016), there were fears that it could lead to significant transmission effects to other countries with robust financial conditions and with no strong fundamental linkages with Greece, due to the presence of contagion effects. A credit event could have disastrous spillover effects for those banking institutions in the Eurozone, which held a significant amount of Greek debt.

However, the Greek debt restructuring (through the PSI) was settled without provoking a subsequent mess. A series of important actions were taken to ensure the orderly debt restructuring. The new bonds issued under English law offered extra protection to the creditors, while the significant amount of cash that was provided to the bondholders through the near-cash EFSF notes contributed to the smoothness of the process. Acting in this direction, the Eurogroup provided Greece with a new loan of EUR 30billion after the PSI, through the EFSF, in order to support and prevent potential losses of the banking system and to restore normality. Conclusively, while ex ante we expected that after a debt restructuring, the new bad equilibrium was more likely to be worse in the period after the PSI due to agents' irrational behavior; ex post we provided evidence that this was not proven to be true in the case of Greece. The contagion effects across sovereigns and banks have been restricted in the period after the implementation of the PSI program.

We conclude that the PSI was an effective way to mitigate the country-specific risk, before it turned to a systemic risk. The Greek debt exchange, through the PSI, has historic significance because it introduced a new record in terms of restructured debt volume and aggregate creditor losses easily surpassing previous ones (Zettelmeyer et al., 2013). Our results showed that the PSI and the way Greece restructured its debt, give us a template that is readily applicable to be used by other Eurozone countries if needed, as they share the same key characteristics (over 90 per cent of their stock of debt is governed by local law) and banks are the main creditors.

The following two essays are interrelated. Starting with Essay 2, we provided a definition for the cost of internal finance that was also used for the specification of the cost differential between external and internal finance. The latter has a key role in the operation of the balance sheet channel, where its operation enhances the effects of a monetary policy shift on the real economy. The cost differential substitutes the concept of the external finance premium. This premium which is extensively employed in the relevant literature is defined as the difference between the borrowers' cost of raising external finance, and, the opportunity cost of using internally generated funds, which is not the same as the cost of internal finance. This approach implies that the cost of external finance should be higher than the cost of internal finance, because there is a cost for lenders to overcome credit market imperfections that should be passed over to borrowers.

We highlighted the conceptual distinction between the cost and the opportunity cost of internal finance. For this reason, we used the return on retained earnings to firm owners, in order to measure the cost of internal finance. Based on the new definition, the external finance premium is not necessarily positive, but rather it represents a cost differential between external and internal finance. This occurs because retained earnings belong to the shareholders of the company. The cost of retained earnings or, alternatively, the return these earnings are expected to generate, should be related to the return required by shareholders on new equity. Our measure for the cost differential retains the countercyclical property of the external finance premium as defined in the literature, and its role in a financial accelerator mechanism is similar to the one proposed by Bernanke, Gertler and Gilchrist (1999).

We also used our definition of the cost of internal finance for the measurement of the equilibrium real interest rate, based on a single-variable method. The equilibrium rate is defined as the real interest rate that is consistent with full utilization of resources in the economy and price stability. It is often measured as the hypothetical real rate that would prevail in the long run, once all of the shocks affecting the economy would have died out. Its precise estimation is a controversial issue. Our estimation is based on asset returns data. We consider that in equilibrium the stock of retained earnings remains constant and there is no flow of retained earnings but only a depreciation flow that keeps the capital stock constant.

Thus, we defined the equilibrium interest rate as the ratio of the depreciation flow, i.e. the amount of earnings required to finance capital consumption of the period, to the stock of retained earnings. We showed that the equilibrium real interest rate displays a downward-sloping trend in the US economy for the period from the first quarter of 1980 through the second quarter of 2017. Our estimates are in accordance with other measures of the equilibrium rate (Laubach and Williams, 2016; Lubik and Matthes, 2015). The unprecedented low level of the equilibrium real interest rate during the recent global financial crisis indicates that the monetary policy tools that could be used in order to reverse the adverse crisis effects and to reinforce the real economic activity were restricted. Thus, the monetary authorities proceeded to a series of unconventional monetary policy measures, which were mainly aimed at longer-term interest rates. Short-term interest rates almost reached a zero lower bound and remained there until late 2015.

The last essay aimed to quantify the amplifying effects of monetary policy changes on total output due to the operation of the credit channel, and, to examine the potency of its two components, i.e. the bank lending and balance sheet channels, in the U.S. over the period 1994:Q1 to 2017:Q2. This was accomplished by using the definition of the cost of internal finance that was introduced in the previous essay. We showed analytically that both channels that work complementary to the operation of the conventional interest rate channel, amplify the effects of a monetary policy change on total output, in relation to the case where only the interest rate channel is operational. The effect is lower when only the balance sheet channel is operational.

Our model, based on the Bernanke and Blinder (1988) model, allowed us to disentangle shifts in loan supply from shifts in loan demand and to identify shifts in the demand for retained earnings, which is a prerequisite for testing the operation of the bank lending and balance sheet channels simultaneously. In our theoretical framework, necessary conditions for the identification of the two components of the credit channel are the existence of imperfect substitutability between external sources of finance (bank lending channel) as well as between internal and external sources of finance (balance sheet channel), due to the presence of information asymmetries.

In particular, by using multivariate cointegration techniques and based on the identified cointegrating relationships among the aggregate time series, we were able to capture the amplifying effects of the aforementioned monetary transmission channels. We imposed and tested a number of appropriate over-identifying theoretical restrictions on the estimated cointegrating vectors that capture the necessary conditions needed for the operation of the bank lending and balance sheet channels. According to recursive and breakpoint stability test results, we separated the sample period in two parts, setting the breakpoint at the fourth quarter of 2008, so as to ensure parameter constancy.

Our results indicated that only the balance sheet channel was operational during the pre- and post-crisis periods in the U.S.. We did not find evidence for the operation of the bank lending channel for the whole sample period. The non-operation of the bank lending channel could be attributed to the significant increase of the degree of asset substitutability and the market-dominated globalized financial system Moreover, variables, such as loans and bonds as percentage of GDP and holdings of bank-related assets to other intermediated assets, provide evidence that bank intermediation is at a low level in the US financial system. Therefore, it is expected that under these conditions the bank lending channel would not be operative. Interpreting the effects of a monetary policy shift on total output, through the operation of the monetary transmission channels, especially during a turbulent period, is crucial for monetary policy authorities in order to proceed to the required policy/reforms that could stimulate real economy.