The Basel Capital Requirement Puzzle: A Study of Changing Interconnections between Leverage and Risk-Based Capital Ratios

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Abstract

Basel regulators have received widespread criticism for failing to prevent two credit crises that hit the U.S. over the last two decades. Nonetheless, banks were considerably overcapitalized prior to the onset of the 2007-2009 subprime crisis compared to those which had undergone the 1990-1991 recession. Therefore, if capital requirements were achieved prior to the subprime crisis, how could the Basel framework be blamed again for having accelerated if not caused another credit crunch? In this paper, we find that the answer to this puzzle lies in the changing dynamics between two different regulatory requirements, the capital ratio and the leverage ratio. Indeed, we show that the change in risk-weight on residential mortgages which was introduced in the Basel II framework was sufficient to reverse the correlation pattern between both ratios; in turn, this resulted in a change to the binding constraint on banks. We also demonstrate that these dynamics are governed by a formula linking the two ratios together which derives from the sensitivity of the risk-based capital ratio to a change in its risk-weight(s). One implication of our work regarding the Basel III regulation consists in validating the newly established capital increments in a mathematical rather than heuristical approach.

JEL classification: G21 G29

Keywords: Capital Ratio, Leverage, Basel

1. Introduction

The Basel Committee on Banking Supervision (BCBS) has been widely criticized for not meeting its bank safety objective after the U.S. witnessed two credit crunches in a span of less than twenty years. Indeed, after the introduction of Basel I (BCBS (1988)), banks struggled to meet the newly established risk-based capital requirements and hence shifted their portfolio composition towards safer assets to boost their capital ratios (CRs). This resulted in a lending contraction during 1990-1991 recession, hereafter referred to as the first crunch.

In contrast, since the Basel II framework (BCBS (2004) and BCBS (2006)) maintained the pre-established CR requirements at 4% and 8% for Tier 1 and Total CR respectively[1], it seems that

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[1]Some risk-weight ccomponents of the CR, however, did change between both regulations.

banks willingly increased their CRs beyond the target thresholds prior to the second crunch (Milne (2002)). Indeed, according to Chami and Cosimano (2010), in the early stages of the subprime crisis, the top 25 banks in the U.S. and Europe had a Tier 1 capital ratio of 8.3% and 8.1% while the Total capital ratio was 11.4% and 11.6%, respectively. At international level, Demirguc-Kunt et al. (2010) find median values of 9.7% and 11.9% for each ratio. However, one change to the risk-weight on residential mortgages is believed to have driven banks towards larger investment in that asset class (Cathcart et al. (2013b)). Due to the distortionary incentives created by holding such high capital buffers (or moral hazard as indicated by Brinkmann and Horvitz (1995)), banks reached dangerous leverage ratios[2] (LR) judging by the standards established by the main U.S. regulators (OCC, FDIC and FED) for well-capitalized institutions. Indeed, Gilbert (2006) states that up until mid-2005 only the two largest U.S. banks did not fall below the 5% leverage requirement.

As a result, once defaults began their domino effect which triggered the second credit crunch in 2007-2009, banks were unable to absorb some of the losses through their capital cushions. It was however not the insufficiency of capital, but rather the quality of its constituents, which became the main concern. In addition, liquidity as well as various other "regulatory loopholes"[3] were scrutinized; the subsequent amendments forming a major part of the Basel III overhaul.

In light of these events, the effects of capital have been investigated from two different perspectives. The first is related to the impact on lending growth (Bernanke and Lown (1991); Peek and Rosengren (1992, 1994, 1995a,b); Barajas et al. (2004); Cathcart et al. (2013b)) whereas the second focuses on risk incentives (Koehn and Santomero (1980); Furlong and Keely (1987); Kim and Santomero (1988); Furlong and Keely (1989); Keely and Furlong (1990); Gennotte and Pyle (1991); Shrieves and Dahl (1992); Calem and Rob (1999); Blum (1999); Montgomery (2005); Berger and Bouwman (2013))[4]. Opinions remain mixed as to the effect capital can have in each case[5]. This exacerbates the puzzle of linking both crunches to the Basel capital requirements given the banking industry complied with the regulation at the start of the second crunch.

This suggests that resolving this puzzle could potentially benefit from a change in perspective. In fact, our literature survey revealed that authors alternate between the use of the CR or LR in their studies. However, the two ratios are not entirely independent as the interaction between both can lead to some interesting findings and a new perspective on relating the abovementioned crunches to the effects of capital. In this paper, we complement the existing literature by exploring a three-step procedure whereby a bank's binding constraint can be affected by changes in the correlation pattern between LR and CR, which in turn is explained by the sensitivity of the latter to alterations in its risk-weights.

Firstly, in order to showcase the shifts in banks' binding constraints between the two crunches, we conduct a bank failure analysis in relation to the CR and LR requirements. While one might

[2]Leverage is not to be confused with the traditional corporate finance definition as the ratio of debt to equity. In the regulatory context it is defined as the ratio of equity to assets (see section 2). In that sense, high leverage is considered to be a good sign.

[3]These terms were attributed to items which were considered missing from the Basel framework. These include the supervisory role of Credit Rating Agencies and Special Purpose Vehicles which were not formally bound by any jurisdiction under the Basel II agreement.

[4]Note that all but the last citations in each literature perspective relate to the first crunch which underlines the greater attention attributed to the Basel regulation following this period.

[5]Though some studies have shown that capital can relate to other bank-specific features such as size. In this case, the perception seems to be that larger banks have smaller CRs (Hall (1993), Estrella et al. (2000), Gilbert (2006) and Demirguc-Kunt et al. (2010)). Still, this finding can depend on the choice of capital measure: Tier 1 VS Total (Demirguc-Kunt et al. (2010)).

consider bank failure as being the adverse consequence of excessive risk-taking, not all failures can be attributed to banks' risky behavior with regard to capital adequacy[6]. Since the existing literature investigated the causal linkages to the subprime crisis outside the realm of risk-based capital requirements, our study re-emphasizes the effects of these requirements on failures in an aim to fill the gap.

Secondly, we investigate reversals in correlation patterns between LR and CR. We show that these patterns are related to economic fundamentals such as lending and GDP which allows us to pinpoint the loan category mostly correlated with the second crunch. Also, in this context, it is common for some authors to confuse correlation for causality, an opinion shared with Furfine (2000). We therefore assess any implied causality using Granger tests.

Thirdly, we derive a partial differential equation (PDE) related to the sensitivity of the CR which combines the two capital requirements. The closed-form solution of this equation can assist policy-makers in setting adequate rather than heuristic targets for the CR and LR. This can also shed light on the controversy highlighted by various authors (Hall (1993); Thakor (1996); Blum (2008); Buehler et al. (2010); Blundell-Wignall and Atkinson (2010); Kiema and Jokivuolle (2010)) regarding the effects of combining the two capital measures. In turn, this has implications on the Basel III regulation which seeks to incorporate the LR as a "backstop" measure alongside the CR.

In order to validate our three-step procedure we proceed as follows. In section 2, we describe our dataset. In section 3, we illustrate the impact of the CR and LR requirements on bank failures for the second crunch period. In section 4, we explore the changes in correlation patterns between the two ratios. Finally, in section 5, we explain the correlation reversals between the two crunches from a theoretical and empirical standpoint. In section 6, we conclude with our main results and policy implications.

2. Data

Our dataset is based on FDIC Call Reports[7] for the periods 1990Q1-1991Q2 and 2004Q3-2009Q2. The latter period covers the second crunch but also contains a control period to allow for some delay before some of the Basel II regulatory changes took place (Cathcart et al. (2013b)). This is not possible for the first crunch as risk-weight data is unavailable prior to 1990.

Due to limited variability in the upper percentiles of the data, our first sample includes CRs up to the 90th percentile. In our second sample we limit the distribution to the 50th percentile to maintain a reasonable amount of observations. In both samples, we discard all negative CR values in order to remove the effect of outliers. Descriptive statistics are shown in Table I below.

These statistics allow us to re-assert the finding in Chami and Cosimano (2010) that banks were indeed better capitalized before the second crunch compared to the first by around two percentage points as indicated by both capital ratios. Moreover, had the regulators linked the CR and LR together by any linear association (for instance, CR - LR $>$ Constant), we would expect similar distributions for each ratio. However, this is not the case as can be seen at the 90th percentile[8] with the quasi-normal distribution of the CR (Skewness ≈ 0, Kurtosis ≈ 3) versus a positively

[6]Operational risk, for instance, has been at the helm of many investigations: fraud (Daiwa, Sumitomo), rogue trading (Barings Bank).

[7]Also known as Reports of Condition and Income taken from the Federal Financial Institutions Examination Council (FFIEC).

[8]Clearly, the sample distribution is no longer normal at the 50th percentile.

skewed and leptokurtotic distribution for the LR (Skewness ≈ 2, Kurtosis varies according to the period). This indicates that there might be a non-linear linkage between the two ratios which we develop in our last section.

Table I:
Summary Statistics

The data in this table relates to the beginning of each designated crunch period, 1990Q1 and 2004Q3. Values are shown after cleansing the data with respect to the CR at the 90th and 50th percentiles. Risk-weighted assets (RWA), Total Assets (TA) and Mortgage Assets (A) are in USD.

Panel A: 1990Q1

Pct	90%					50%				
Var	Obs	Mean	Std Dev	Skew	Kurt	Num Obs	Mean	Std Dev	Skew	Kurt
CR	12069	12.5	4.3	0.5	3.0	6714	9.5	2.1	-1.2	4.7
LR	12069	8.0	2.5	1.8	33.1	6714	6.7	2.0	5.2	155.2
RWA	12069	2.5^{8}	2.6^{9}	45.8	2903.8	6714	3.9^{8}	3.4^{9}	34.5	1636.1
TA	12069	3.1^{8}	2.5^{9}	34.9	1731.8	6714	4.8^{8}	3.3^{9}	26.6	997.0
A	12069	1.0^{8}	7.7^{8}	30.3	1198.2	6714	1.6^{8}	1.0^{9}	23.3	697.5

Panel B: 2004Q3

Pct	90%					50%				
Var	Obs	Mean	Std Dev	Skew	Kurt	Num Obs	Mean	Std Dev	Skew	Kurt
CR	8440	14.4	4.7	0.5	3.3	4077	10.7	1.3	-0.5	4.4
LR	8440	9.5	2.6	2.1	15.6	4077	8.1	1.2	2.2	40.2
RWA	8440	7.5^{8}	1.0^{10}	34.6	1408.7	4077	1.3^{9}	1.5^{10}	24.4	697.0
TA	8440	9.9^{8}	1.3^{10}	36.1	1528.0	4077	1.7^{9}	1.9^{10}	25.6	759.5
A	8440	3.3^{8}	3.9^{9}	33.5	1421.2	4077	6.1^{8}	5.5^{9}	24.4	742.8

The survivorship bias is apparent in our study as can be seen from the one-third reduction in the number of banks between both periods[9]. Furthermore, we witness an order of magnitude increase in the value of assets due to balance-sheet expansions, mergers and acquisitions.

3. The Change in Binding Capital Constraint

3.1. Capital, the Common Numerator

The CR and LR are the most popular measures of capital adequacy. Since the two ratios are proportional to Tier 1 capital by definition[10], we can investigate changes to capital from the perspective of either ratio.

Greenspan et al. (2010) have shown that by the year 2000 the LR of the commercial banking sector had fallen to almost a fifth of its value two centuries ago[11]. This was followed by a period in which the market-valued LR was almost double its book value. However, the second crunch witnessed a full reversal of this trend. Since one can cast out the possibility of an increase in the market value of assets during crisis times, the only explanation for the fall in market-valued LR, must relate to a depreciation in the value of capital. That is mainly because of the failure of some capital components to play their role as loss absorption layers. As a matter of fact, this gave Basel

[9] We do not account for this bias in order to preserve the data at our disposal as the higher moments already match up to a certain extent between the two periods.

[10] With reasonable approximation based on the risk-based capital definitions for Prompt Corrective Action (PCA) as posted by the FDIC, CR = K/RWA; LR = K/A where K is Tier 1 Capital. See section 4 for more details.

[11] This corresponds to an increase in the conventional sense of Debt/Equity.

III regulators the incentive to scrap the Tier 3 capital layer altogether and remove all elements in Tier 2 that cannot fulfill their purpose[12]. Consequently, this gave more importance to the role of Tier 1 capital.

3.2. The Capital Ratio (CR) versus the Leverage Ratio (LR): The Binding Constraint

In view of the common capital feature embedded in both ratios, any changes between the two can be attributed to changes in their denominators, risk-weighted versus unweighted assets. However, each of the CR and LR can have very different effects on a bank's behavior depending on which of the two is the binding constraint (Berger and Udell (1994), Hancock and Wilcox (1994), Peek and Rosengren (1994), Chiuri et al. (2002), Barajas et al. (2004), Blundell-Wignall and Atkinson (2010)). Before pointing out which of the two ratios was primarily responsible for destabilizing the banks during the second crunch, we start with a review of the first crunch which attracted most of the attention in terms of bank failure analysis with regard to capital regulation.

First, it is important to recognize that the substitution of the 1980s flat rate for the risk-based capital (RBC) standard under Basel I meant that banks accounting for a quarter of total assets failed the newly imposed regulation according to Avery and Berger (1991). Based on Berger and Udell (1994), this amounted to a 20% increase in banks not abiding by the regulation. Moreover, Peek and Rosengren (1994) emphasized that, towards mid-1991, from the 20 largest First District commercial and savings banks, the numbers violating the targets on Tier 1 and Total capital were zero and seven, respectively.

Unlike the fixed CR targets, the choice of which LR is chosen to compare between banks is at each author's discretion. This is because CAMEL ratings, which guide national regulators in their discretionary LR requirement for each bank, are not disclosed[13]. This point is emphasized by Hall (1993) who demonstrated that if the average LR were assumed at 3%, the CR becomes the more likely first crunch culprit since most banks are able to fulfill the LR requirement. However, if the LR were established at a level of 5% then at least 18% of these would fail the leverage target.

Two studies which investigated the impact of the CR and LR on bank failures during the first crunch are Avery and Berger (1991) and Estrella et al. (2000). Although the latter study came at a much later time than the former, it only pointed out the critical regions at which banks were affected by one ratio or the other. Hence, no consideration was given to the combined effect of the two ratios. However, one important observation we make from the authors' results is that at least one year prior to its failure, a bank can have the same LR in the critical region as one which eventually survived. This supports the fact that the LR has no predictive power regarding bank failures in contrast to the CR, in line with the authors' conclusion. However, it is important to make sure this statement remains valid during the second crunch.

Avery and Berger (1991) make a similar assessment by which they calculate the number of banks that went bankrupt just before the start of the first crunch given that these banks had earlier failed to meet one or more of the CR and/or LR regulations. For example, almost a third of the 6% of banks which could not meet the targets for Tier 1 capital, Total capital or leverage failed over the next 2 years[14]. More importantly, 50% of all banks failing the Tier 1 target eventually

[12]Mainly some types of preferred stock categorized under hybrid instruments.

[13]Under this rating scheme, the safest banks, attributed the best rating of 1, are given a leverage target of 3%. Depending on their condition, all other banks are set a target of either 1 to 2 percentage points higher. Even if it were known, the function underlying the "CAMEL-to-Leverage" specification is arguably not bijective.

[14]Note that in the Basel framework, if a bank fails Tier 1 it automatically fails the Total requirement as the regulators impose that Tier 2 cannot exceed 50% of Tier 1.

went bankrupt, putting this requirement at pole position in terms of forecasting power.

Following the same line of thought as the previous authors we analyze the relationship between these capital standards and bank failures for the second crunch. This complements findings such as those of Berger and Bouwman (2013) who observed that a one standard deviation decrease in capital more than doubles the probability of bankruptcy. However, their result shows this trend as being linear even though authors which differed on their assessment of risk and capital (Koehn and Santomero (1980); Furlong and Keely (1987); Kim and Santomero (1988); Furlong and Keely (1989); Keely and Furlong (1990)) still agreed that capital shortfalls weigh more on a bank's survival rate than surpluses.

Notwithstanding some components might have changed, the CR thresholds were not altered between the two Basel frameworks. This allows for a better comparison with Avery and Berger (1991). However, instead of exploring changes before and after the Basel II capital standards were brought in, our study uses three intervals (pre, mid and end of the crisis), in order to gauge the evolution in meeting these standards along with the leverage requirement as the crisis unfolded. As per Avery and Berger (1991) and Hall (1993), we also look at a range of leverage targets 3%, 4% and 5%. Finally, we look at how combinations of both standards impact on bankruptcies.

Table II shows a number of compelling findings. First, with respect to the 4% (median) leverage requirement, Avery and Berger (1991) had obtained a 94% estimate of the proportion of banks that passed all three requirements prior to the first crunch. This is still well below the corresponding 99% proportion at the onset of the second crunch which confirms the same result obtained by Greenspan et al. (2010). What's more is that the percentage of banks failing any of the standards was at least an order of magnitude less than those in Avery and Berger (1991)'s first crunch estimates. This confirms that, in quantitative terms, banks were holding capital well in excess of the targets (overcapitalization) prior to the second crunch.

Nevertheless, failing any of the standards in the last crunch had more serious repercussions since a much greater proportion of the pre-crunch bank pool ($> 50\%$) ended up bankrupt. Ultimately, all banks failing either the Tier 1 CR or a 3% LR went bankrupt. Therefore, since meeting either of the requirements did not make up for falling short of meeting the other, this brings back into question the purpose of imposing dual requirements. Moreover, we point out the increase in the failure to meet any of the requirements over time. This contrasts with a simultaneous decrease in bankruptcy rate, specifically between the start and end of the period under observation. The first finding stresses the weakened capital position of banks eroded by losses throughout the crunch period. The second finding relates to corporate finance theory in that survival rates increase for banks which can endure more phases of a crunch (Klapper and Richmond (2011)).

A striking feature is that during all three phases of the crunch, all banks that failed Tier 1, and obviously Total, capital also failed the average leverage requirement of 4%. This has crucial implications on Basel III as it suggests that the choice of imposing a backstop 3% requirement could be overly conservative. More importantly, increasing the leverage standard by 1% always resulted in an average doubling of the failure to meet the requirement across all periods. These reasons are why leverage emerges as the binding constraint for this crunch; thus statistically corroborating the statements in Gilbert (2006)[15] and Blundell-Wignall and Atkinson (2010). This is in contrast with the first crunch where banks were mostly struggling to meet their CR requirements.

[15]Though the author uses a different definition for the binding capital requirement based on surpluses rather than the actual number of banks that achieved the given target.

Table II:
Bankruptcy Predictions from Banks Failing to Meet Various Capital Standards

Our results for the period 2004Q3-2009Q2 are broken down into three consecutive dates (pre, mid, end of crisis). With regard to the overall sample, we account for the bank percentage in terms of number (%B) and assets (%A). Each row consists of a different regulatory target. Numbers in brackets are for use in the last rows as combinations of the previous single standards where ‖ denotes the logical OR and & is the logical AND. The last row is for banks which passed all standards (with a 4% LR). In that case, the following identity can be applied: Prob[Pass] = 1 - Prob[(1)‖(2)‖(4)].

	Pre-crisis (2007Q2)			Mid-crisis (2008Q2)			End-crisis (2009Q2)		
Standard	%B	%A	%Bkrpt	%B	%A	%Bkrpt	%B	%A	%Bkrpt
Tier1-CR(1)	0.02	0.00	100.00	0.10	0.25	88.89	0.49	0.37	30.23
Total-CR(2)	0.10	0.12	55.56	0.25	0.11	63.64	0.94	0.37	12.20
3%-LR(3)	0.03	0.02	100.00	0.09	0.01	62.50	0.47	0.31	31.71
4%-LR(4)	0.07	0.05	66.67	0.15	0.25	46.92	0.89	0.45	27.27
5%-LR(5)	0.14	0.15	69.23	0.39	0.34	42.86	1.42	0.85	17.89
(1)‖(2)‖(4)	0.14	0.15	61.54	0.37	0.35	66.67	1.45	0.74	18.25
(1)&(2)&(4)	0.02	0.00	100.00	0.10	0.25	88.89	0.49	0.37	30.23
Pass	99.86	99.85	7.02	99.63	99.65	3.38	98.55	99.26	0.49

3.3. Assessing the Basel III Changes from the Perspective of Capital Shortfall

When quantifying the magnitude of failing a specific standard one must relate it to surpluses, or alternatively shortfalls[16]. As a matter of fact, Brinkmann and Horvitz (1995) emphasize that regulators should not only look at how many banks are likely to fail a newly introduced standard but also by how much their (excess) capital cushion would vary. Hence, one motivation for performing the following study is to assess the adequacy of the new Basel III standards.

Focusing on shortfall is arguably a better choice then surplus. Firstly because, as was evoked earlier, the fact that banks were overly capitalized prior to the crunch did not fare well for some of them during the crunch. In other words, while size does matter for the regulators, it does not reflect quality of capital. This means that surplus could be a biased signal for the health of the banking sector. Secondly, shortfall is more amenable to the idea of setting minimum capital requirements. Hence, in the same spirit as Hancock and Wilcox (1994), we calculate the average shortfall as the difference between the target ratio and the actual ratio of banks which failed to meet any of the CRs. This turned out to be equal to 1.5% for Tier 1 and 1.4% for Total Capital[17] (conditional on having met Tier 1).

The Tier 1 shortfall is actually in line with the current steps taken by the Basel III Committee to increase the Tier 1 requirement by 2%. While the Total CR is set to remain at the existing 8% target level, this ratio is being supplemented by other capital buffers[18] bringing the overall requirement well above the shortfall of the recent crunch.

Finally, if the Basel III regulators had decided to abide by the median 4% leverage requirement implemented in the U.S., this could end up short of expectations as our estimates for the second crunch revealed a close to 1% LR shortfall. This could explain why the regulators chose the absolute

[16]Regulators classify institutions into four main capital surplus/shortfall categories: Adequately/Under capitalized and Significantly/Critically undercapitalized.

[17]Note that the average shortage also decreased towards the end of the crunch due to the increase in number of failed banks.

[18]This will raise the target to between 10.5% and 15% via the conservation, countercyclical and TBTF systemic buffers.

difference, 3%, as a conservative target for minimum compliance of all banks. Moreover, our finding suggests that the CAMEL ratings system should be revised upward by the same shortfall amount to reflect the median bank's actual leverage position. Note that this is only until the U.S. becomes fully compliant with Basel III as the introduction of the new framework is bound to render the regulators' rating system obsolete.

4. The Change in CR and LR Correlation Patterns

4.1. Pattern Reversals and Economic Fundamentals

Having illustrated one crucial change between the two crunches with respect to the shift in binding capital constraint from CR to LR, we now move on to another differentiating aspect. To find out if there is any pattern in the co-movements of banks' LR and CR we plot the correlation between both ratios over each crunch period in Figures 1 and 2.

Various authors have measured this correlation over specific periods without mentioning if the obtained pattern is likely to be persistent over time. For instance, Estrella et al. (2000) perform their calculations for the first crunch only. Their yearly values coincide to a large extent with the ones we obtain for the first quarter of each year in Figure 1. To our knowledge, they are the first to have observed an imperfect correlation between the two capital measures which hints to the fact that each ratio can provide independent information on capital adequacy for a given bank.

Our estimates are calculated on the basis of the 90th percentile sample in Table I and broken down into each bank size category[19]. Note how in both crunches (Figures 1 and 2), the small bank correlation pattern moves closely with that of all banks put together. This is a characteristic of the data as small banks accounted for almost 72% and 44% of banks in the sample on average during the first and second crunch, respectively. Note that, the fall in the number of small banks between crises was partially compensated for by a rise in medium banks from 25% to 48%. However, the latter were more reflective of the overall correlation pattern in the first crunch than in the second. We attribute this unexpected finding to the static nature of our choice of size thresholds and the survivorship bias reflecting that many banks were either removed or merged with other medium/large banks. Indeed, medium banks show a closer connection with larger ones during the second crunch (Figure 2).

Nonetheless, the essential component of this analysis is with regard to the different overall correlation pattern trends for each of the crises. Excluding the reversals in the first and last quarters of each period, during the first crunch (Figure 1), the trend is monotonously decreasing while the opposite is true for the second (Figure 2). The intuition for this result lies in the CR definition which, by construction, is affected by the balance of assets between risky and safe categories (see section 4). Note that with regard to the size of the fluctuations, during the first (and shorter) crunch, the difference in correlation between peak and trough is double that in the second.

In addition, it seems as though each crunch period's correlation pattern between LR and CR, (hereafter referred to as ρ), is itself correlated with various economic fundamentals, starting with loan growth. As in Berger and Udell (1994) and Shrieves and Dahl (1995), we categorize lending growth into three major groups: real estate (LNRE), commercial and industrial (LNCIUSD) and

[19] As per Berger and Udell (1994), large banks were those with more than \$1 billion in assets, medium were those with assets between \$100 million and \$1 billion, while small banks were the ones with less that \$100 million.

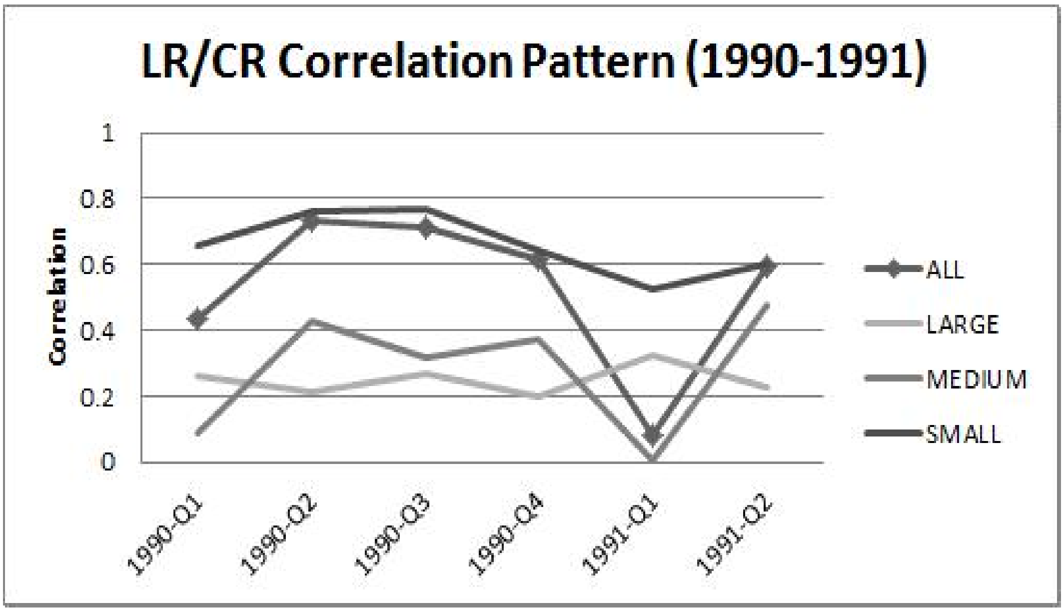

Figure 1: Correlation Pattern between LR and CR for different size banks during the 1990-1991 crunch

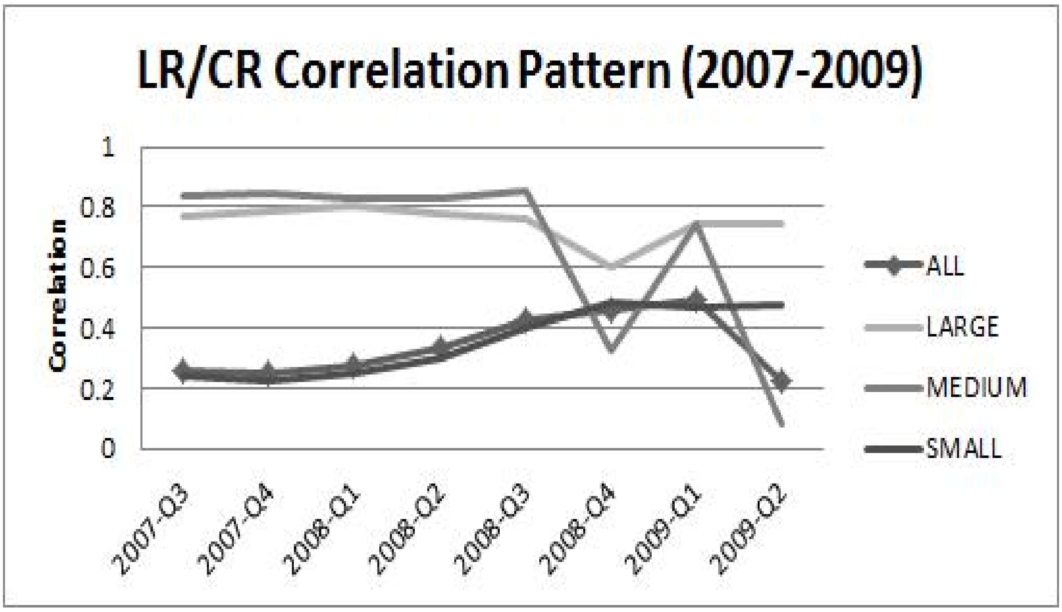

Figure 2: Correlation Pattern between LR and CR for different size banks during the 2007-2009 crunch

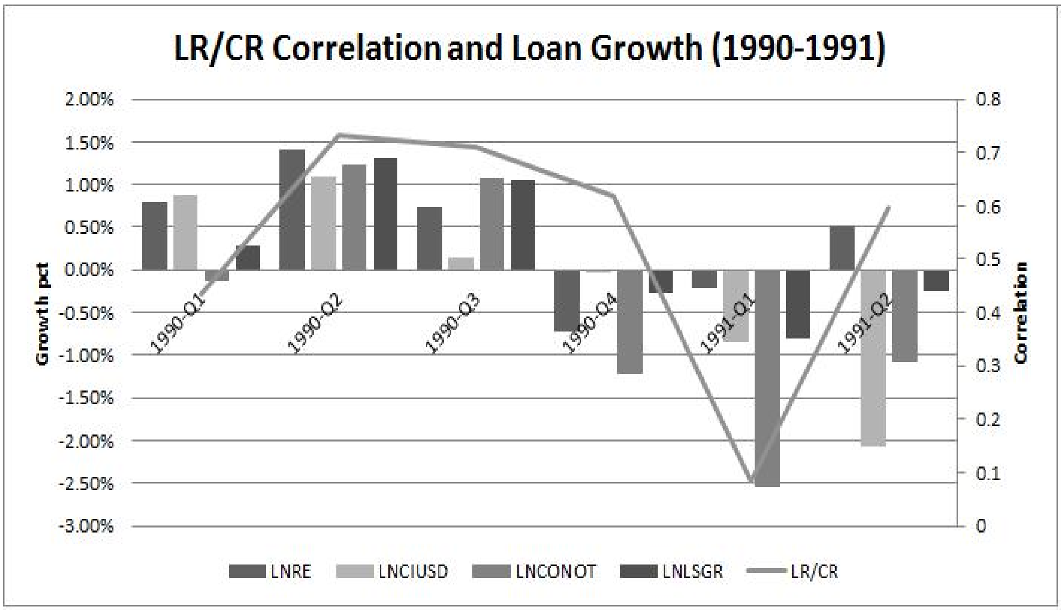

Figure 3: Relation between LR/CR Correlation Pattern (ρ) and Loan Growth for different loan categories during the 1990-1991 crunch

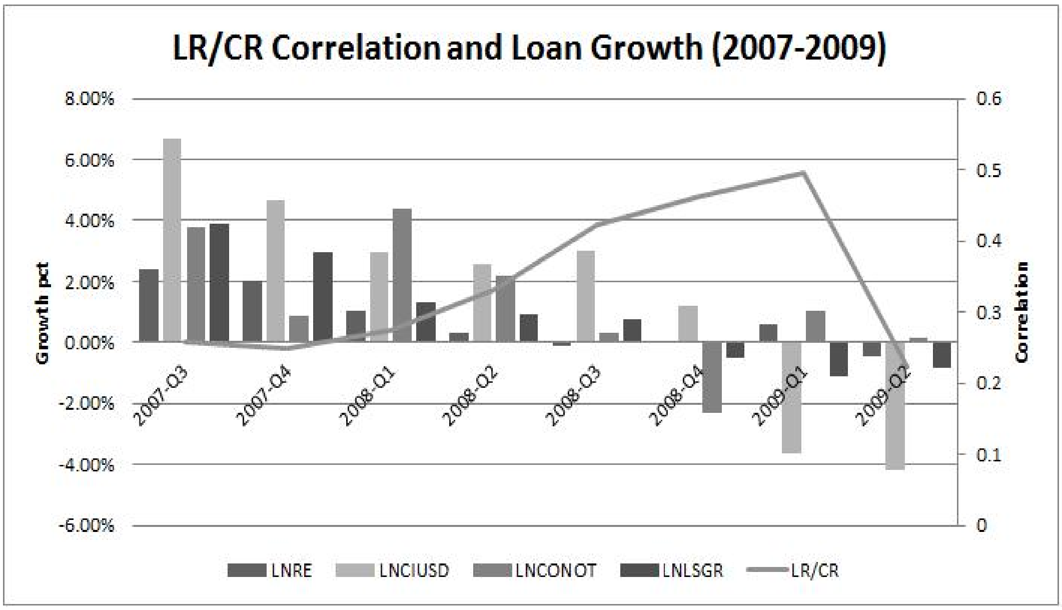

Figure 4: Relation between LR/CR Correlation Pattern (ρ) and Loan Growth for different loan categories during the 2007-2009 crunch

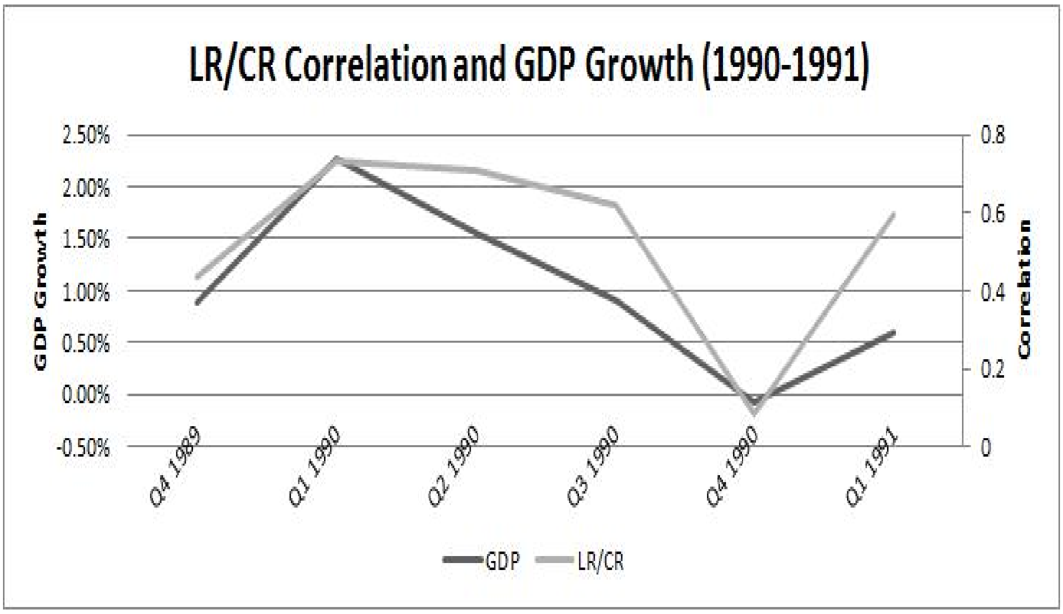

Figure 5: Relation between LR/CR Correlation Pattern and GDP for different loan categories during the 1990-1991 crunch

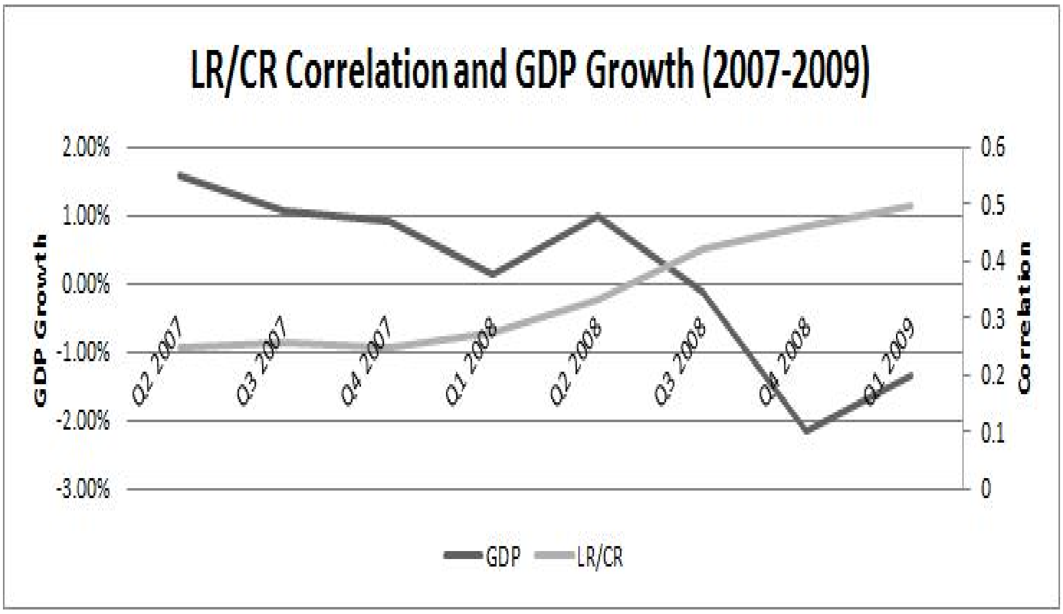

Figure 6: Relation between LR/CR Correlation Pattern and GDP for different loan categories during the 2007-2009 crunch

consumer (LNCONOTH) loans. We also include the aggregate (LNSGR) which accounts for the loan categories we just stated as well as other types of loans. As is apparent during the first crunch, the correlation between ρ and the overall[20] loan growth pattern is positive (Figure 3). The opposite is true during the second crunch where the two are negatively correlated (Figure 4). This hints to a change in the dynamics between the two ratios and lending during the two crunch periods.

Our next step is to capture the loan category mostly linked to each of the crises by computing the correlation of each category with the LR/CR correlation pattern (ρ), denoted as "Correl". The results for each category are shown in Table III. Total loans and consumer lending alternate in first place (in absolute value) in each crunch, followed by real-estate and commercial lending. Note as well that the correlation between ρ and the real estate category is relatively closer to that with the overall loan portfolio during the second crunch (0.44 and 0.75, respectively) compared with that of the first (-0.49 and -0.61, respectively). This illustrates the differential role this asset class played during each crunch.

Table III:
Correlation between ρ and Loan Asset Growth

The results in this table refer to the correlation between various loan asset classes and the observed LR/CR pattern (ρ) for each designated crunch period.

Loan Asset Class	Crunch 1 (1990Q1-1991Q2)	Crunch 2 (2007Q3-2009Q2)
LNRE	0.44	-0.49
LNCIUSD	0.28	-0.32
LNCONOTH	0.80	-0.54
LNSGR	0.75	-0.61

Finally, the reversals witnessed earlier in the correlation patterns can be shown to be an artifact of the data which could relate to our choice of the exact start and end dates of each crunch. In order to do so, we introduce a macroeconomic variable, GDP growth, to represent the state of the economy. However, one could argue that in a financial crisis, macro-effects take longer to appear in the economy than at the micro-bank level. For this reason, we use a one-quarter lagged LR/CR pattern (ρ) instead of the concurrent one and plot it alongside GDP in Figures 5 and 6. Again, despite the exceptional GDP improvements in 2008Q2 (before the Lehman crash) and 2009Q1 (before an improvement in lending had been recorded), the correlation patterns between the lagged ρ and GDP match almost perfectly in both the first (Correl = 0.83) and second (Correl = -0.47) crunches. In sum, this highlights the fact that the correlation between CR and LR (ρ) is associated with lending and the economic cycle.

4.2. Establishing the Line of "Causality": Granger Tests

To determine whether the LR/CR process influences the loan growth pattern or vice versa, we look at the components of the CR. Denoting K as Tier 1 capital, it is apparent from equation (1), the more the bank invests in assets ($A_i = 1$) with high risk-weight ($w_i = 1$), the more the CR tends towards the LR:

[20] Although one cannot infer from observing these figures which of the loan growth categories is mostly correlated with ρ, the lending contraction is obvious in both figures. We look at the individual categories next.

$$\lim_{w_i \to 1} CR = \lim_{w_i \to 1} \frac{K}{\sum_{i=1}^{N} w_i A_i} = \frac{K}{\sum_{i=1}^{N} A_i} = LR \tag{1}$$

Moreover, we consider two case scenarios for the value of the risk-weight on real-estate loans: the first being that of a high risk-weight, W_{LNRE} (Equation (2)); while the second is that of a low risk-weight, w_{LNRE} (Equation (3)).

$$W_{LNRE} : \nearrow \frac{\Delta L}{L} \implies CR \to LR \implies Correl > 0 \tag{2}$$

$$w_{LNRE} : \nearrow \frac{\Delta L}{L} \not\Longrightarrow CR \to LR \not\Longrightarrow Correl > 0 \tag{3}$$

Again based on the equation (1), the higher the risk-weight on real-estate the more the CR tends towards the LR if lending increases in that category. We can then expect, ceteris paribus, a more positive correlation ("Correl"), between the LR/CR correlation pattern (ρ) and lending growth. Indeed, that was the case for the 1990-1991 crunch where the risk-weight on real-estate was at a high of 50%. In contrast, during the 2007-2009 crunch, which saw the Basel II risk-weight fall from its previous level of 50% down to 35% (Blundell-Wignall and Atkinson (2010)), we expect CR to dissociate from LR. This allows us to infer that loan growth might influence the LR/CR correlation pattern, according to the level of the risk-weight.

We verify the postulates above via Granger causality tests[21].. We run a basic VAR[22] model between loan growth and ρ. The results in Table IV show the causal effect between the two factors depending on which is chosen as the dependent/independent variable. The sign of "Correl" will effectively be given by the sign of the slope between the two variables[23]. The loan growth category mostly correlated with the LR/CR pattern (ρ) is determined via the Akaiki Criterion. We perform this analysis for each crunch.

We observe that for the first crunch the line of causality goes from the loan growth categories towards ρ. This can be seen through the p-values (and R^2) which are significantly lower (higher) than those of the reverse causal relation. This can be interpreted as a rejection of the Granger hypothesis of non-causality. Note that the AIC and β coefficient are the highest in magnitude in the case of the LNRE category as expected from our initial postulates regarding the role of mortgage lending. What is more important is the positive sign given by β which is a clear indicator of the pattern we observe in Figure 3.

The picture is not as clear during the second crunch as for some loan categories, the causal relation seems to have been reversed. Yet, what matters to us is that in the case of LNRE which is the best-fit AIC model, the first crunch direction of causality is preserved. More importantly, the β sign becomes negative which points to the opposite correlation pattern we observe in Figure 4. Hence it appears that this transformation in correlation patterns was not random and could therefore have been caused by a differentiating aspect between both crises.

[21]Note that we could have done the same correlation using lagged GDP instead of loan growth. However, the relationship between the CR and GDP is not that straightforward.

[22]Using only 1 lag to limit the time effect of any variable on the next since they are expected to vary simultaneously. In spite of the small number of observations, the results we obtain are consistent with our reasoning.

[23]This comes from the basic econometric relation $\beta = Correl(x, y) \times \frac{\sigma_y}{\sigma_x}$ where the variances σ_i are positive.

Table IV:
Causal link between Loan Growth and LR/CR Correlation (ρ)

The first two columns in this table refer to the variables in the VAR model. β is the slope coefficient, while AIC gives the overall goodness of fit.

Panel A: Crunch 1 (1990Q1-1991Q2)

Dependent	Indepent	β	t-stat	p-val	R^2	AIC
ρ	LNRE	33.86	12.93	0.000	0.97	-9.56
LNRE	ρ	-0.02	-1.81	0.070	0.47	-9.56
ρ	LNCIUSD	29.49	12.87	0.000	0.82	-9.16
LNCIUSD	ρ	-0.00	-0.13	0.094	0.42	-9.16
ρ	LNCONOT	31.45	19.08	0.000	0.99	-9.20
LNCONOT	ρ	-0.08	-2.55	0.011	0.66	-9.20
ρ	LNSGR	31.54	11.27	0.000	0.97	-9.53
LNSGR	ρ	-0.03	-1.65	0.098	0.50	-9.53

Panel B: Crunch 2 (2007Q3-2009Q2)

Dependent	Independent	β	t-stat	p-val	R^2	AIC
ρ	LNRE	-12.84	-4.13	0.000	0.74	-10.40
LNRE	ρ	-0.00	-0.13	0.893	0.70	-10.40
ρ	LNCIUSD	3.16	2.12	0.034	0.47	-6.62
LNCIUSD	ρ	-0.30	-3.64	0.000	0.84	-6.62
ρ	LNCONOT	-2.74	-1.35	0.176	0.33	-7.05
LNCONOT	ρ	-0.207	-3.01	0.003	0.56	-7.05
ρ	LNLSGR	-2.25	-0.48	0.634	0.20	-7.74
LNSGR	ρ	-0.05	-0.80	0.422	0.81	-7.74

5. Explaining the Changes using the CR sensitivity to Risk-Weight

In order to explain the correlation reversals we highlighted in the previous section, we assess whether the two ratios LR and CR have any influence on each other. Furfine (2000) claims that the same magnitude change in either ratios can lead to drastically opposite effects in terms of portfolio risk. Similarly, Gilbert (2006) states that changing the risk-weights in the CR would impact the number of banks bound by the LR despite the fact that the latter is insensitive to risk-weights by definition. More specifically, using the exact scenario that occurred prior to the subprime crunch, in other words a reduction in the risk-weight attributed to first-lien residential mortgages[24], the author shows that a risk-weight lowering lead to an increase in the number of banks bound by the LR. This is a clear illustration of how the interaction between the two ratios can lead to a change in the binding constraint. In what follows, we undertake a mathematical approach in order to explain the LR/CR correlation pattern reversals.

5.1. Deriving the relationship between CR and LR

The ratio of Risk-Weighted Assets (RWA) to Total Unweighted Assets (TA) in equation (4) is commonly used as a measure of risk as it is bound between 0 and 1 in increasing order of credit risk. This is because RWA tends towards TA as the proportion of risky assets (high risk-weight) increases (see Equation (1)). Note that this tendency drives the CR toward the LR, which explains how the two ratios can move together. Based on that, what is not noted in most of the recent

[24] Although the author's specification changes the original value of 50% to half its value, rather than the one chosen by Basel of 35%.

literature which uses this credit risk proxy (Van-Roy (2005), Hassan and Hussain (2006), Berger and Bouwman (2013)) is that it is equivalent to an interaction between the CR and LR, irrespective of capital K[25], as shown in equation (4). This will be useful in deriving the formula presented next.

$$\frac{RWA}{TA} = \frac{\frac{K}{CR}}{\frac{K}{LR}} = \frac{LR}{CR} \tag{4}$$

In the next step, the change in CR is derived with respect to a change in risk-weight, w_i, affecting a certain asset category i out of a pool of N categories[26]. As can be seen from Equation (6), this change is negatively related to the product of the CR and a second term which is dubbed "asset proportion" (AP_i). This term refers to the "proportion" (in currency amount) held by the asset whose risk-weight is being changed vis-a-vis the total amount of risk-weighted assets.

$$\begin{aligned}
\frac{\delta CR}{\delta w_i} &= \frac{\delta}{\delta w_i}\left(\frac{K}{\sum_{i=1}^{N} w_i A_i}\right) = K \times \frac{\delta}{\delta w_i}\left(\frac{1}{\sum_{i=1}^{N} w_i A_i}\right) \\
&= -K \times \left(\frac{A_i}{(\sum_{i=1}^{N} w_i A_i)^2}\right) = -\frac{K}{\sum_{i=1}^{N} A_i} \times \frac{\sum_{i=1}^{N} A_i}{\sum_{i=1}^{N} w_i A_i} \times \frac{A_i}{\sum_{i=1}^{N} w_i A_i} \\
&= -LR \times \frac{1}{\frac{RWA}{TA}} \times \frac{A_i}{RWA} \qquad (5) \\
&= -LR \times \frac{1}{\frac{LR}{CR}} \times AP_i = -CR \times AP_i \qquad (6)
\end{aligned}$$

The formula has intuitive appeal as the product of terms is always positive and hence the change in CR resulting from a positive change in w_i is always negative since an increase in risk-weight means more risky assets which implies a negative (positive) shock to the CR numerator (denominator) resulting in an overall decrease. Hence, in anticipation of such an artificial increase, regulators should not have maintained the same CRs after lowering the risk-weight on residential real-estate loans under Basel II. Instead, they should have increased the CR targets even further to maintain adequate capital buffers. While some might argue that this strategy could have exacerbated the crunch by increasing the contraction in lending, it might have proven worthwhile in weathering it by having forced banks to hold higher loss-absorption layers. Arguably, this has been taken into consideration under Basel III in the setting of the new CRs.

Note that the breakdown of the CR sensitivity into multiple product variables is in the same spirit as Van-Roy (2005) and Hassan and Hussain (2006)[27]. One interesting feature which is apparent from equation (5) is that the sensitivity of the CR to a change in risk-weight is higher in absolute terms the higher the LR, the safer the bank in terms of credit risk (low RWA/TA), and the larger the affected asset proportion (AP_i). Hence, equation (5) provides the mathematical framework to highlight the importance of the credit risk ratio and asset proportion in dampening or intensifying the sensitivity of the CR. The reason why the safest banks are the most sensitive

[25] Kamada and Nasu (2000) are the closest to reach this result as they use Total capital in the definition of the CR versus Tier 1 capital for the LR. This leads to a different but related concept: the asset quality index.

[26] Prior to Basel II, N=4 for i∈[0, 20, 50, 100].

[27] However, the authors' derivations are with respect to CR itself, i.e. CR growth rather than with respect to a change in risk-weight.

to changes in CR can be understood in the context of an extreme scenario where the risk-weights are at zero. In that case, the CR is immune to changes in any amount of assets. However, any deviation in risk-weight away from zero is likely to perturb it significantly.

So far, our derivations highlight the dependence of the CR on the LR, affected by a negative sign for the case of a change with respect to a single risk-weight category, w_i. Note that the Basel II framework looked at shifting various risk-weights by introducing new possible categories[28]. It is easy to show that the relationship between the CR and LR can be extended to all N categories which yields the following formulae in equations (7) and (8). We notice that most terms were adapted from the previous single risk-weight case, with the last factor being the product of asset proportions. Our focus, however, is on the previous negative sign, which now changes to a sinusoidal pattern of positive/negative signs depending on the number of affected risk-weight categories. This captures, along with the factorial term[29], the interactions between different changes in risk-weights.

$$\frac{\delta CR}{\delta w_1 ... \delta w_N} = (-1)^N \times N! \times LR \times \frac{1}{\frac{RWA}{TA}} \times \prod_{i=1}^{N} AP_i \quad (7)$$

$$= (-1)^N \times N! \times CR \times \prod_{i=1}^{N} AP_i \quad (8)$$

One reason why these formulae are useful is that if we single out one major change between Basel I and II as being the decrease in risk-weight on residential real-estate mortgages, then the "new" CR effectively becomes sensitive to an additional risk-weight category. This takes N in the previous equations from four to five which is sufficient to reverse the sign in the CR sensitivity equation. In turn, this forces the reversal in correlation patterns (Correl) seen in the previous section. Note that while the correlation between LR and CR (ρ) remains positive, the sensitivity of the CR, as captured by its derivative(s), could change which explains the variations in slope found in Figures 1 and 2. In sum, our finding depends on the total number and sign (positive/negative) of all possible changes affecting the risk-weight categories. We note as well that the behavior of the function in the new CR sensitivity equations is indetermined as N tends to infinity. However, this is not an issue for a few number of risk-weight categories as is normally the case. Hence, short of adopting a continuous method, our method will prove helpful if regulators decide to improve the granularity of the risk-weight scheme.

5.2. Model Verification and Policy Implications

5.2.1. The CR 3-Factor Model

In this section, we set out to test whether the 3-factor relation in equation (5) can empirically explain the sensitivity of the CR to a change in a single risk-weight. Using the derivative decomposition rule we can write:

$$\frac{\delta CR}{\delta w_i} = \frac{\delta CR}{\delta t} \times \frac{\delta t}{\delta w_i} \Rightarrow \frac{\delta CR}{\delta t} = -\frac{\delta w_i}{\delta t} \times LR \times \frac{1}{\frac{RWA}{TA}} \times \frac{A_i}{RWA} \quad (9)$$

[28] Those were 35%, 75%, 150% and 300%.

[29] This term arises from the successive derivations with respect to the risk-weights.

To disentangle the effect of each factor in the equation we take logarithms at both ends. This translates into the following empirical model where the intercept α should equal the logarithm of the change in risk-weight which is constant for all banks in a given period:

$$ln\,(\Delta CR)_j = \alpha + \beta_1 ln(LR)_j + \beta_2 ln(InvCrRatio)_j + \beta_3 ln(AP)_j + \epsilon_j \tag{10}$$

Using Newey-White robust estimators, we verify the findings of this model by comparing the cross-sectional estimates from the two periods in Table I which differ by the timing of one crucial event. The 1990Q1-1992Q2 period was marked by the phasing-in of Basel I with the shifting of the risk-weight on residential real estate mortgages from 100% to 50%. However, although the Basel II change from 50% down to 35% began to be factored in by U.S. banks between 2004Q3-2009Q2, the actual deadline for enforcing it would come later on[30]. In our empirical framework, in order to precisely detect changes in risk-weight, we make two key assumptions. Firstly, any change in single risk-weight would occur on a specific date and enforced by all banks simultaneously. Secondly, that the banking sector actually sets its ratios according to the identity in equation (5). If these assumptions are verified, the first crunch should exhibit a noticeable difference at phase-in date compared to the second.

Running the model at various sample percentiles as per Table I shows remarkably no difference for both periods. We therefore suffice with the results from the 90th percentile which are displayed in Figures 7 and 8 below[31]. These figures show the ability of the theoretical model to explain on average around 12% of the changes in CR. This suggests that in practice these changes are also governed by other exogenous factors or frictions which can arise from the fact that the LR and CR do not move in total freedom due to the constraint imposed by regulators on minimum thresholds. As such, our first assumption is probably not true.

Moreover, both crises show persistent coefficients for the inverse of the credit ratio while asset proportion barely has any effect in both periods. Despite the fact that both variables are a function of RWA, we base our finding on the fact that this component might have been factored in only by the credit ratio as a well-known determinant of the CR, while the importance of asset proportion was highlighted by equation (5). As such, our second assumption is also not likely to true.

Nevertheless, the crucial finding is how the coefficient on LR ($\beta 1$), Alpha_UC (α) and R^2 rise in the same way at exactly the point in time where the regulation was phased-in during the first period: after the end of 1990 (or beginning 1991) according to Woo (2003). While this pattern almost perfectly matches with the reverse correlation pattern in Figure 1, there is no such perceivable change for the second crunch as seen from Figure 2. We also note that, during the first period, the $\beta 1$ adjusts to around its expected value of 1 at the phase-in point.

Empirically, we observe a (1%) significant value of 4.3 for the unconstrained α (Alpha_UC) in 1991Q1 which is almost twice as high as the ones obtained throughout the corresponding period. However, despite also being significant, our value of 4.6 changes relatively little during the second period and does not exhibit the same noticeable change as in the first period. This refutes our first assumption in that banks either did not change their risk-weight or rather did so continuously over the second period. Our model derivation in equation (10) implies that we should detect an α

[30] The worldwide full implementation of Basel II was scheduled for 2011 (Berger et al. (1995)) which came a year after Basel III was endorsed.

[31] Note that since the regulatory variables were introduced in 1990Q1 and we are looking at changes in capital ratios, this implies that we would lose one observation in this designated period.

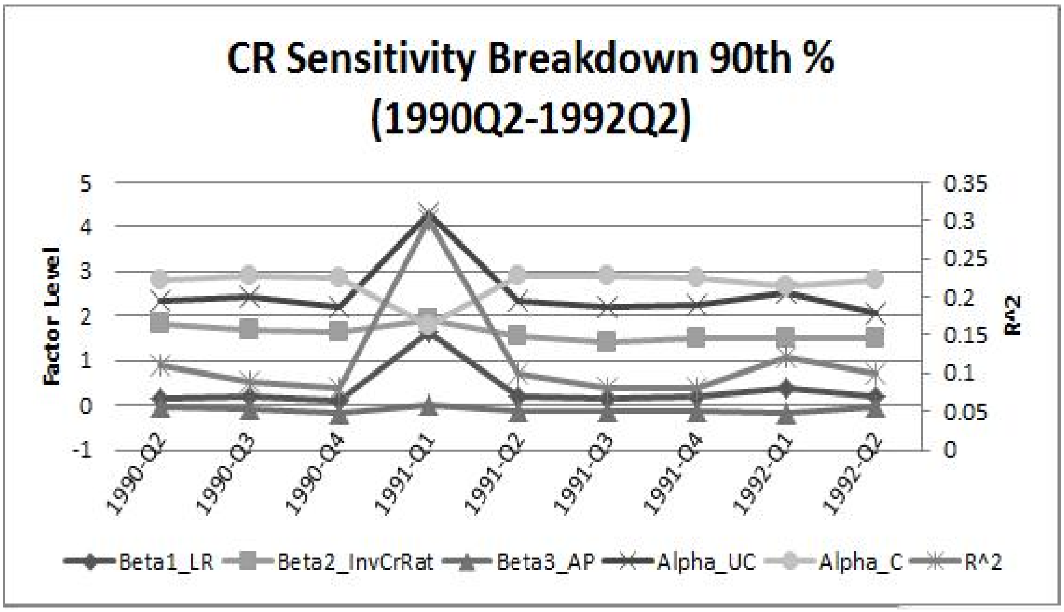

Figure 7: Three Factor Model for the CR sensitivity to a change in Risk-Weight during 1990Q2-1992Q2

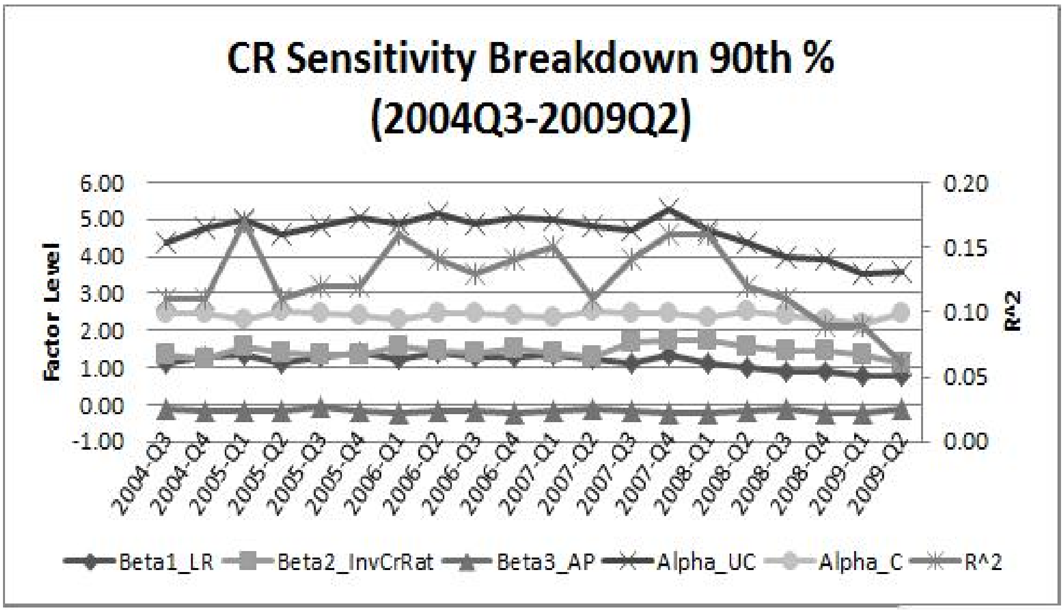

Figure 8: Three Factor Model for the CR sensitivity to a change in Risk-Weight during 2004Q3-2009Q2

of 3.9 (2.7) for the first (second) period[32]. However, these values did not prevail owing to the fact that our assumptions are not true in practice. Nonetheless, this comparison between both periods confirms that banks ratios still account for instantaneous changes in risk-weight which our model is sensitive to.

Note that our empirical findings are only valid for changes in a single risk-weight which could not always be the case. Our results could have therefore been affected by disturbances from unaccounted changes. Hence, we force the theoretical constraint that all coefficients be equal to 1 in equation (10). On one hand, the constrained α (Alpha_C) in the first period still undergoes a perceivable change in 1991Q1, falling to around 1.8. This indicates that our constrained model remains sensitive to the single change in risk-weight. On the other hand, while the constrained α in the second period is almost the same as its expected value at around 2.4, the fact that it remains almost constant over time suggests again that banks did not undertake a specified change in risk-weight during this period.

5.2.2. Linking the CR to the LR: Policy Implications

In this section, we derive a framework for explicitely setting the CR with respect to the LR. Our starting point is equation (8) which is a simple homogeneous partial differential equation (PDE) that can be solved in closed form. The derivations are stated in the Appendix. In the case of a single risk-weight change, the relationship becomes:

$$CR = LR \times e^{\sum_i^N [AP_i(1-w_i)]} \tag{11}$$

As the exponential power term is always positive, the CR should always be greater than the LR. Indeed, the formula implies that banks should at least meet a lower threshold of CR at least equal to LR; afterwards, they should increment their respective risk-based capital positions by a weighted average of their asset proportions as captured by the exponential term in equation (11). For example, with a 3% LR, the old Tier 1 CR of 4% is reasonable but for the less conservative LR of 5% it is not. Indeed, such distortions to the above identity could induce wrongful behavior on the part of banks as was reported earlier in Gilbert (2006). Hence, as the CR is set to increase to 6% under Basel III, this is in line with both LR targets of 3-5%, assuming appropriate asset proportions.

In the following, we test to what extent equation (11) holds empirically using the following panel regression. Our results are shown in Table V.

$$ln\left(\frac{CR}{LR}\right)_{jt} = \alpha + \beta \sum_i^N [AP_i(1-w_i)]_{jt} + \epsilon_{jt} \tag{12}$$

We report that across the two sample periods all estimates are significant at the 1% level. As can be seen from panels A and B, at the 90th percentile, the R^2 increases to 93% (74%) for the first (second) periods. The relationship then weakens the smaller our sample becomes as this makes it more specific to a particular type of banks. This confirms that the above relationship holds for the banking sector taken as a whole. Moreover, we notice that the α converges to 0 (1 in anti-logarithmic terms) as suggested by our theoretical model. This confirms the lower threshold

[32]These values are equivalent to ln(-(50-100)/1) and ln(-(35 - 50)/1).

of CR being at least equal to LR[33] before any increments linked to asset proportions take effect.

Furthermore, we run a Chow test on the second period to verify that the coefficients are stable between pre-crisis and crisis periods with the delimiter date set to 2007Q3[34]. The results shown in Panel C illustrate that in most cases, the hypothesis of stability cannot be rejected which means that our model is valid independently of the period under consideration[35]. Nevertheless, even at its peak of 0.4, the value of β is noticeably below 1. In other words, a good proportion of banks are operating below the theoretical CR requirement. This leaves policy-makers with the task of driving them upwards to ensure the synergy between the two ratios is maintained.

Note that according to equation (4), CR/LR is equivalent to TA/RWA; hence our results should hold whether we use either ratio as the LHS variable in equation (12). Indeed, we rerun our robustness test version of our model in Table VI and find that we reproduce to a large extent the results in Table V.

Finally, our results showed that the Basel III guidelines with respect to CR increments are in line with the theoretical implications of our model. They also highlight that there is room to improve on the choice of capital targets by making them more adequate using a dataset of representative banks to calibrate a generalized model for the banking sector. Alternatively, this could create the possibility for having endogenous bank-specific requirements rather than a one-size fits-all guideline; a change called for by some critics since the birth of the Basel regulation. Notably, this would help European regulators especially in the context of establishing homogeneous capital requirements for all EU countries (Cathcart et al. (2013a)).

Table V:
Testing the CR formula stability (CR/LR)

The results in this table are obtained after running the original version of the regression model in Equation 12: $ln\left(\frac{CR}{LR}\right)_{jt} = \alpha + \beta \sum_i^N [AP_i(1-w_i)]_{jt} + \epsilon_{jt}$. Pct denotes the percentage remaining from the original sample after removal of outliers. Chow tests are based on the delimitor date 2007Q3.

Panel A: 1990Q1-1992Q2

Pct	100%	99.9%	99%	95%	90%	80%	70%	60%	50%
α	0.445	0.445	0.195	0.136	0.119	0.109	0.100	0.095	0.086
β	0.108	0.108	0.420	0.497	0.521	0.533	0.543	0.547	0.557
R^2	0.458	0.458	0.898	0.924	0.928	0.917	0.906	0.893	0.885

Panel B: 2004Q3-2009Q2

Sample	100%	99.9%	99%	95%	90%	80%	70%	60%	50%
α	0.368	0.376	0.371	0.345	0.131	0.116	0.115	0.116	0.107
β	0.038	0.037	0.035	0.056	0.438	0.452	0.437	0.411	0.411
R^2	0.175	0.111	0.075	0.370	0.742	0.674	0.600	0.509	0.546

Panel C: Chow Tests

Sample	100%	99.9%	99%	95%	90%	80%	70%	60%	50%
$\beta 1$	0.038	0.038	0.036	0.056	0.439	0.454	0.441	0.416	0.418
$\beta 2$	0.040	0.043	0.040	0.051	0.424	0.438	0.423	0.399	0.398
p-val	0.585	0.002	0.005	0.151	0.000	0.001	0.002	0.003	0.003
$\chi 2$	0.3	9.19	7.8	2.06	12.7	10.3	9.59	8.4	8.48

[33]This can be seen by taking the Taylor series approximation for small numbers. For example, using the 50th percentile in Panel A: exp(0.086) $\approx$ 1+0.086 = 1.086 $\approx$ 1.

[34]Choosing a different date such as 2006Q3 in relation to the Basel II implementation does not change our results.

[35]At the 90th percentile where the hypothesis is rejected, the coefficients are still equal up to one decimal place.

Table VI:
Testing the CR formula stability (TA/RWA)

The results in this table are obtained after running a parallel version of the regression model in Equation 12: $ln\left(\frac{TA}{RWA}\right)_{jt} = \alpha + \beta \sum_i^N [AP_i(1 - w_i)]_{jt} + \epsilon_{jt}$. Pct denotes the percentage remaining from the original sample after removal of outliers. Chow tests are based on the delimitor date 2007Q3.

Panel A: 1990Q1-1992Q2

Pct	100%	99.9%	99%	95%	90%	80%	70%	60%	50%
α	0.442	0.442	0.192	0.133	0.116	0.106	0.097	0.092	0.083
β	0.105	0.105	0.416	0.494	0.517	0.529	0.538	0.542	0.553
R^2	0.457	0.457	0.897	0.924	0.928	0.917	0.906	0.894	0.8866

Panel B: 2004Q3-2009Q2

Sample	100%	99.9%	99%	95%	90%	80%	70%	60%	50%
α	0.367	0.374	0.351	0.343	0.129	0.114	0.113	0.115	0.105
β	0.038	0.037	0.059	0.056	0.437	0.451	0.436	0.411	0.412
R^2	0.177	0.111	0.421	0.371	0.743	0.674	0.601	0.510	0.547

Panel C: Chow Tests

Sample	100%	99.9%	99%	95%	90%	80%	70%	60%	50%
$\beta1$	0.038	0.038	0.060	0.056	0.438	0.454	0.440	0.416	0.418
$\beta2$	0.040	0.043	0.053	0.051	0.424	0.437	0.423	0.399	0.398
p-val	0.694	0.002	0.059	0.171	0.000	0.001	0.001	0.003	0.003
χ^2	0.15	9.14	3.56	1.87	12.48	10.34	9.75	8.69	8.83

6. Conclusion

In this paper, we investigate the impact a change in risk-weight can have on the behavior of banks towards adjusting their CRs and LRs. We first assess which of these latter two ratios was the binding constraint on banks prior to the 1990-1991 and 2007-2009 credit crunches. Our results indicate that unlike the first crunch, the LR was more to blame for triggering the subprime crisis. Our work complements the analysis of Avery and Berger (1991) and reveals the impact of crises on bank capital cushions, and vice versa. More specifically, we illustrate the erosion in capital ratios caused by the subprime crisis while establishing the beneficial impact of capital on survival rates.

Furthermore, we illustrate the reversal in correlation patterns between the two ratios which we deem is at the heart of the change in binding constraint. The correlation patterns are seemingly related to loan growth (microeconomic) and GDP (macroeconomic with appropriate lag) market signals. We show that this reversal has its roots set in a mathematical relation emerging from the sensitivity of the CR to a change in its risk-weight(s). Singling out the change with regard to the residential mortgage asset class which happened before the onset of the second crunch can help explain the change in these patterns.

Finally, we provide a formula that relates the sensitivity of the CR to the LR, the inverse of the credit risk ratio, and a new factor conveniently dubbed "asset proportion". An extension of that formula gives way to a first-order homogeneous partial differential equation (PDE) governing the behavior of the CR. We solve for single and multiple changes in risk-weights which fit into a generic closed form solution. This allows for setting adequate CRs which reflect changes in risk-weights while taking into consideration its counterpart capital measure, the LR. In fact, this can be done in a straightforward and rigorous manner with not much added complexity compared to enforcing arbitrary Basel ratios. Hence, this allows us to move away form the use of heuristics with regard to capital target selection.

In sum, the results of our research are helpful in assessing the improvements brought by the new Basel III regulation with respect to capital requirements. Considering the ongoing efforts of improving the granularity of the risk-weight scheme by introducing new risk-weight buckets, our framework will facilitate the setting of adequate CRs. Hence, doing so in a mechanical rather than heuristic way could eliminate the Basel capital ratio puzzle related to the diverse impact of regulatory capital on banks.

Appendix A. Solution to the CR equation

Assuming the CR is a function defined on $]0,1]^N$ with N possible risk-weights (w_i), the solution to the partial differential equation (PDE) in equation (8) is solved in the exponential form $Ae^{\sum_{i=1}^{N} c_i w_i}$ where c_i are arbitrary constants to be found. Let $g(w_1, ..., w_N)$ be another function defined on the same support as CR and representing the product term in the equation ($\prod_{i=1}^{N} AP_i$). Substituting into (8) we get:

$$\prod_{i=1}^{N} c_i = (-1)^N \times N! \times g(w_1...w_N) \tag{A.1}$$

As stated earlier, the only boundary condition we have is regarding the sensible approximation that CR(1,...,1) $= Ae^{\sum_{i=1}^{N} c_i} =$ LR. Denoting by n the subset of N asset categories with respect to which we are calculating the sensitivity of the CR, this yields a system of two equations with n+1 unknowns. We solve for the cases of n=1, n=2 and n=N.

Appendix A.1. Solution with n=1

The system of equations for the case of a single risk-weight change becomes:

$$\begin{cases} c_i = -g(w_i) & \text{(A.2)} \\ LR = Ae^{\sum_{i=1}^{N} c_i} & \text{(A.3)} \end{cases}$$

By substitution:

$$LR = Ae^{\sum_{i=1}^{N} c_i} \rightarrow A = LR \times e^{-\sum_{i=1}^{N} c_i} \tag{A.4}$$

$$CR = LR \times e^{-\sum_{i=1}^{N} c_i} \times e^{\sum_{i=1}^{N} c_i w_i} = LR \times e^{-\sum_{k\neq i}^{N} c_k + AP_i} \times e^{\sum_{k\neq i}^{N} c_k w_k - AP_i w_i} \tag{A.5}$$

$$= LR \times e^{-\sum_{k\neq i}^{N}[c_k(1-w_k)] + AP_i(1-w_i)} \tag{A.6}$$

By symmetry, the same form applies for a change in asset j which gives:

$$CR = LR \times e^{-\sum_{k\neq j}^{N}[c_k(1-w_k)] + AP_j(1-w_j)} \tag{A.7}$$

By the ratio of the two changes in assets we get the following identity:

$$1 = e^{-\sum_{k\neq i}^{N=1}[c_k(1-w_k)] + AP_i(1-w_i) + \sum_{k\neq j}^{N}[c_k(1-w_k)] - AP_j(1-w_j)} \tag{A.8}$$

Taking logarithms at both ends and applying the principle of linearity we get: $c_k = -AP_k$ for all asset classes. This gives the final version of the CR equation given below. Note how the riskiest risk-weight class has no bearing on the differential between CR and LR in the same way that the safest risk-weight category has no impact on total RWA.

$$CR = LR \times e^{\sum_{i=1}^{N}[AP_i(1-w_i)]} \tag{A.9}$$

Appendix A.2. Solution with n=2

The boundary condition remains the same. Hence, using symmetry to overcome the under-specification in the case of 3 risk-weight categories, the system of equations for the case of any two risk-weight changes becomes:

$$\begin{cases} c_i c_j = 2 \times g(w_i, w_j) = 2 \times AP_i AP_j & \text{(A.10)} \\ c_j c_k = 2 \times g(w_j, w_k) = 2 \times AP_j AP_k & \text{(A.11)} \\ c_k c_i = 2 \times g(w_k, w_i) = 2 \times AP_k AP_i & \text{(A.12)} \end{cases}$$

Combining these equations together we get: $c_i^2 = 2AP_i^2, c_j^2 = 2AP_j^2, c_k^2 = 2AP_k^2$. This gives two possible solutions; however the first solution (A.13), is discarded as the CR is increasing in w_i which is counter-intuitive.

$$CR = LR \times e^{-\sum_{i=1}^{N}[\sqrt{2}AP_i(1-w_i)]} \tag{A.13}$$

$$CR = LR \times e^{\sum_{i=1}^{N}[\sqrt{2}AP_i(1-w_i)]} \tag{A.14}$$

Appendix A.3. Solution with n=N

Similarly, using symmetry and discarding the erroneous cases for n even, we obtain the general solution as below.

$$CR = LR \times e^{-\sum_{i=1}^{N}[\sqrt[N]{N!}AP_i(1-w_i)]} \tag{A.15}$$

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